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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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CORRELATION OF PENNSYLVANIAN FORMATIONS OF NORTH AMERICA

BY THE PENNSYLVANIAN SUBCOMMITTEE OF THE NATIONAL RESEARCH COUNCIL COMMITTEE ON STRATIGRAPHY, R. C. MOORE, *Chairman*, H. R. WANLESS, J. M. WELLER, J. STEELE WILLIAMS, C. B. READ, W. A. BELL, G. H. ASHLEY, M. G. CHENEY, L. M. CLINE, G. E. CONDRA, R. H. DOTT, C. O. DUNBAR, M. K. ELIAS, L. C. GLENN, F. C. GREENE, T. A. HENDRICKS, J. M. JEWETT, J. H. JOHNSON, P. B. KING, J. B. KNIGHT, A. I. LEVORSEN, H. D. MISER, N. D. NEWELL, F. B. PLUMMER, M. L. THOMPSON, C. W. TOMLINSON, AND JEROME WESTHEIMER.

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ABSTRACT

The substance of this contribution is a comprehensive chart of Pennsylvanian rocks that undertakes to summarize present knowledge and judgment of classification and correlation of these Late Paleozoic strata, which most American geologists consider properly classifiable as a system. Evidence bearing on differentiation of major divisions and annotations explaining correlations are

presented briefly. The correlation chart is Number 6 of a series planned and developed through efforts of the National Research Council Committee on Stratigraphy (Dunbar *et al.*, 1942).

INTRODUCTION

GENERAL CONSIDERATIONS

Upper Carboniferous rocks of North America, commonly known as the Pennsylvanian system, constitute a very important segment of the geologic column of this continent, from whatever point of view considered. Their pre-eminent richness in coal deposits is a universally recognized feature of economic importance. Also, the development of continental and marine deposits in unprecedented multiplicity of lateral and vertical variations, accompanied by extreme persistence of many thin sedimentary units and by remarkable cyclic rhythm of deposition in many regions, sets this division of rocks apart. The record of land plants and marine animals of the time is voluminous and well preserved. Structural relations that bear significantly on stratigraphic classification are also discerned.

The Pennsylvanian system offers specially interesting problems in stratigraphic correlation. In many areas these strata can be traced long distances in such a manner that units only a few feet or inches thick can be recognized positively in sections separated by hundreds of miles. In other places it is not now possible to make satisfactory correlations of sections only a few miles apart. Some Pennsylvanian deposits, especially in the western United States, have been studied very little. A collaborative effort to summarize present knowledge of the age and interrelations of these Late Paleozoic formations is represented in work of the Pennsylvanian Subcommittee of the National Research Council Committee on Stratigraphy. During a period of more than 10 years, this subcommittee has fostered studies on the nature of Pennsylvanian deposits. It has sought especially to focus attention on problems of classification and stratigraphic correlation of these rocks. Considerable advancement of knowledge of the Pennsylvanian rocks of North America belongs to the period of the subcommittee's existence, and it is proper to assign credit directly or indirectly to the subcommittee for many important contributions that have been published by individual workers.

The chief objective of the Pennsylvanian Subcommittee has been to prepare a general correlation chart showing as completely as possible the classification and nomenclature applied to Pennsylvanian rocks in all parts of the continent, and indicating as accurately as possible the knowledge or consensus of judgment on correlation of rock units. Development of this project has been slow. Inevitable difficulty attends effort to synthesize the work of two dozen widely scattered collaborators, whatever may be their willingness to participate in a joint enterprise. Accordingly, responsibility for various features of the Pennsylvanian correlation chart is very unequally distributed among geologists who are listed as authors. Chief assistants to the chairman in the labor of organizing the chart have been H. R. Wanless, J. M. Weller, and J. Steele Williams.

ORGANIZATION OF THE PENNSYLVANIAN SUBCOMMITTEE

The Committee on Stratigraphy of the National Research Council, Carl O. Dunbar, chairman, created the Pennsylvanian Subcommittee by appointing Raymond

C. Moore to organize a group of geologists for work on a Pennsylvanian correlation chart. Acceptance of an invitation to participate in this undertaking led to formation of the subcommittee with the following initial membership: George H. Ashley (northern Appalachians), Walter A. Bell (eastern Canada), Monroe G. Cheney (north-central Texas), George E. Condra (northern Midcontinent), Robert H. Dott (Oklahoma), L. C. Glenn (southern Appalachians), Frank C. Greene (Missouri), J. Harlan Johnson (Rocky Mountains), A. I. Levorsen (Midcontinent subsurface), Philip B. King (western Texas), J. Brookes Knight (invertebrate paleontology), Hugh D. Miser (Ouachita region), Raymond C. Moore (Midcontinent and general), Norman D. Newell (northern Midcontinent, invertebrate paleontology), Charles B. Read (paleobotany and Appalachians), J. Marvin Weller (Eastern Interior, invertebrate paleontology), and James Steele Williams (western United States, invertebrate paleontology). These geologists were asked to organize available information on the Pennsylvanian succession of selected areas and to furnish data bearing on correlation. Special field studies were undertaken by several of these individuals, and a number of conferences, both in field and office, were held by groups. Extensive exchange of information and discussion of problems was conducted by correspondence. Important aid in obtaining needed field data was received through research grants from the Penrose Fund of The Geological Society of America, to E. H. Sellards and associates for study of Pennsylvanian and Permian deposits of Texas, to R. C. Moore and associates for similar investigations in the northern Midcontinent region, and to H. R. Wanless for work in the Eastern Interior and Appalachian districts.

During progress of work in making a Pennsylvanian correlation chart, geologists in addition to those already named were called on for help, and these are included as members of the subcommittee: L. M. Cline, C. O. Dunbar, M. K. Elias, T. A. Hendricks, J. M. Jewett, F. B. Plummer, M. L. Thompson, and Jerome Westheimer. Contributions from these men and active efforts of others, especially Bell, Cheney, Condra, Dott, Miser, Moore, Newell, Read, Tomlinson, Wanless, Weller, and Williams, resulted in developing four successive drafts of the chart, which were circulated for criticism and suggested emendation. These drafts served to focus attention on various problems, and they have led to the version here published. Obviously, the chart can only be assigned status as a progress report. Any correlation chart of comprehensive scope lacks finality, and this one treating Pennsylvanian rocks of North America is subject to possibly numerous changes. Inasmuch as war conditions prevent present continuation of work by the Pennsylvanian Subcommittee, it seems desirable to publish the correlation chart in the form now reached.

DESCRIPTION OF CORRELATION CHART

The columns showing the succession of Pennsylvanian strata in different parts of North America have been arranged as closely as possible according to geographic location. Numbering of the columns begins at the left with the Acadian province of eastern Canada. Moving southwestward along the trend of the Appalachian district, higher numbered columns show the Pennsylvanian rocks of this area, then the Eastern Interior coal basin and the northern part of the Midcontinent region. Succeeding columns show sections for Texas, and thence northwestward through the Rocky

Mountains area. Columns representing outcrops in States of the Great Basin and Pacific Border are arranged so as to follow a somewhat zigzag course, and the chart ends in the far northwestern part of the continent, in Alaska. Columns having generally similar classification are brought into adjacent position, but it is not possible to produce an arrangement that satisfactorily brings all closely related Pennsylvanian sequences into adjoining positions on the chart.

The type Pennsylvanian succession is located in the northern Appalachian area, in Pennsylvania. Argument for placement of columns belonging to this region at the left margin of the chart, as a starting point in presenting correlations, is countered by several considerations. Perhaps chief of these is the lack of firmly established major divisions in the type Pennsylvanian column that are fitted to serve as framework for classifying deposits of similar age in other regions. It is desirable, nevertheless, to give prominence to the stratigraphic classification applied to the type section, and this is done by placing columns for Pennsylvania near the starting point of the chart and by emphasizing major lines of division that are based on study of the northern Appalachian sequence. Main divisions generally recognized in the eastern Pennsylvanian sections include (in upward order) Pottsville series, Allegheny series, Conemaugh series, and Monongahela series. These divisions have been designated as formations or groups by various writers. The boundaries between major stratigraphic segments of the type Pennsylvanian section are shown by heavy full lines in columns for the Appalachian coal fields and, except for coincident boundaries, as heavy broken lines in other columns.

Major divisions of the Pennsylvanian recognized in the Midcontinent region comprise the following, named in ascending order: Morrowan series, Lampasan series, Desmoinesian series, Missourian series, and Virgilian series. Boundaries between these parts of the Pennsylvanian section are shown by heavy full lines. The lower boundaries,—those between Morrowan and Lampasan and between Lampasan and Desmoinesian—are correlated with major boundaries in the Appalachian region, but the lines separating higher main divisions of the western Pennsylvanian do not match those at the Allegheny-Conemaugh and Conemaugh-Monongahela contacts.

There are more named stratigraphic units in the Pennsylvanian rocks of North America than in almost any other system. Obviously, most minor units belonging to the various columns cannot be shown on the chart. The divisions named on the chart are those considered to have most importance for correlation or required in order to show the horizon of correlated beds. If one wishes to determine names that are omitted from the chart, he must consult publications that describe the local sections or refer to compilations such as the stratigraphic charts of different states prepared by M. Grace Wilmarth of the U. S. Geological Survey. The Wilmarth charts, though not formally published, are available in most geological libraries of the United States.

A graphic section that has been made to occupy otherwise unused space in the central part of the chart undertakes to show diagrammatically inferred relations of stratigraphic units in the northern Appalachian district to those in the Eastern Interior and northern Midcontinent. Pennsylvanian deposits are believed originally to have extended uninterruptedly across areas between these regions where now they are lacking. Some marine beds probably once were physically continuous from

Oklahoma and Kansas eastward to Pennsylvania and West Virginia. Horizons of marine deposition are separated in the central and eastern United States by continental beds that denote temporary withdrawal of shallow seas. Convergence of strata, overlaps, and positions of supposed major breaks in the succession (unconformities), as indicated in this diagram, are not well enough determined to warrant acceptance of this picture of stratigraphic relations at full face value. It is intended to show correlations and to express the thickness of deposits in the compared sections. The diagram differs from correlations shown in the chart in a few particulars, such as the inferred equivalence of the Brereton and part of the Fort Scott limestones (instead of Brereton-Pawnee), Livingston and Brush Creek (instead of Livingston-Porterville), Omega and Cambridge (instead of Shoal Creek-Cambridge), and Ames and Lecompton (instead of Ames-Stanton). The correlations of the diagram, in these instances, reflect evaluation of fusulinid evidence. Most correlations between West Virginia and Ohio and between Kansas and Oklahoma are firmly fixed, but ties of these regions with Illinois are not well established.

Floral zones are designated in columns at the left edge of the chart. Those for the Pennsylvanian rocks of North America are based on work by C. B. Read, and those for northwestern Europe represent studies by Emily Dix (1937). As shown by David White, C. B. Read, W. C. Darrah, W. J. Jongmans, W. A. Bell, M. K. Elias, and others, there is generally a close parallel between the sequence of fossil plant groups in North America and Europe. This affords ground for correlation of the American section with divisions of the Namurian, Westphalian, and Stephanian in Europe. There is definite evidence that the base of the Upper Carboniferous, as established on the eastern side of the Atlantic at the base of the Namurian, is considerably lower stratigraphically than the base of the Pennsylvanian inasmuch as the lower Namurian (A zone) is Upper Mississippian (Chesterian) in age. Correlations with several representative European Upper Carboniferous successions are indicated on the chart at the left.

Faunal zones based on various groups of marine invertebrates are indicated in columns at the right margin of the chart. This placement suggests the dominance of marine Pennsylvanian deposits in the western part of the continent. Fusulinid zones are fairly well established by the work of C. O. Dunbar, L. G. Henbest, N. D. Newell, J. M. Skinner, M. L. Thompson, M. P. White, and others. This group of fossils has proved very useful for correlation of many marine Pennsylvanian and Permian beds. Fossils less widely used in efforts to define Pennsylvanian zones are various genera and species of bryozoans, brachiopods, crinoids, pelecypods, and cephalopods. The cephalopod zones shown in the chart have been designated by A. K. Miller. Brachiopod zones are indicated on the basis of studies by Weller, Condra, Dunbar, Newell, and Moore. Zone fossils among the crinoids are designated by Moore.

The Pennsylvanian Subcommittee concludes its work with publication of the accompanying correlation chart. It is well understood, however, that a vast amount of work must still be done to produce a reasonably complete correlation chart of Pennsylvanian rocks of North America having satisfactorily well established equivalences. Organized effort to continue studies on Pennsylvanian stratigraphy may be resumed after the war. In any case, geologists who can offer evidence for correction of corre-

lations expressed in the present chart or who have criticism of any features of the chart are invited to contribute their aid toward revision. This may be done either by publishing results of their work or by writing to the Chairman of the Committee on Stratigraphy, Carl O. Dunbar.

Annotations are offered to help geologists in apprehending and evaluating features of the correlation chart. Effort to trace the course of stratigraphic investigations of Pennsylvanian rocks in different areas and to give account of divergent classifications is omitted. Little or no discussion is offered on many unsettled problems of classification and correlation. It is deemed desirable simply to state in as concise manner as possible some of the evidence that supports features indicated in the chart. The task of writing this manuscript has been assumed unwillingly by the subcommittee chairman because handicaps incident to rather arduous military assignments have precluded organization of material in a manner that otherwise would have been possible. Library facilities have not been available. Although war conditions make collaboration of the investigators who contributed to making the Pennsylvanian chart an impracticable means of preparing an adequate joint discussion to accompany the chart, the chairman has consulted subcommittee members as much as possible.

A few references to the literature are made by citation of authors and dates of publication, but no detailed documentation of statements is made.

DEFINITION AND GENERAL CHARACTER OF PENNSYLVANIAN ROCKS

The term Pennsylvanian was originally applied by H. S. Williams (1891, p. 83) to strata of the northern Appalachian region ranging from the base of the "Millstone grit" or Pottsville "formation" to the summit of the "Upper Barren Coal Measures" or Dunkard "formation." Deposits equivalent in age to the type Pennsylvanian in Pennsylvania were also designated by this name. The Pennsylvanian rocks were classed as a series of the Carboniferous system by Williams.

The base of the Pottsville beds is marked by a distinct unconformity throughout most of the Appalachian district. Hence, small difficulty or disagreement has attended recognition of the lower boundary of the Pennsylvanian rocks in the eastern United States. Similarly, Pennsylvanian strata in most other sections of North America are sharply separated from Mississippian or other subjacent rocks. The base of the Pennsylvanian is generally defined by (1) occurrence of an obviously significant structural discordance, (2) an important sedimentary hiatus, (3) a pronounced lithologic change, and (4) readily determined paleontologic evidence. Sections in which the Mississippian-Pennsylvanian boundary is obscure are few.

The upper limit of Pennsylvanian deposits, unlike the lower one, is not well defined except in areas that lack beds of recognized Permian age. The discovery of *Callipteris* and other plants regarded as indicative of Autunian or Rotliegend age in the Dunkard, extending down nearly to the base of this division, led David White and others to the conclusion that the "Upper Barren Coal Measures" should be excluded from the Pennsylvanian and assigned to the Lower Permian. In the Midcontinent region, similarly, the upper Pennsylvanian boundary has been drawn partly on interpretation of paleontologic evidence and partly on arbitrary selection of convenient cartographic datum horizons. The position of the boundary has been differently

placed by successive workers who have chosen various stratigraphic contacts ranging through hundreds of feet of seemingly conformable strata (Moore, 1940). The top of the Pennsylvanian section in Pennsylvania is now generally drawn at the base of the Waynesburg sandstone, which lies conformably or with obscure disconformity on shale that is classed as uppermost Monongahela. In the Midcontinent region, the Pennsylvanian-Permian boundary is now placed at a disconformity that in most complete sections occurs just above the Brownville limestone. This boundary, which locally is marked by prominent deposits of channel sandstone classed as lowermost Permian, separates beds having paleontologic and lithologic characters like those of undoubted Pennsylvanian from overlying strata having different characters. *Pseudoschwagerina*, *Callipteris*, and other fossils considered to indicate Permian age make appearance above the unconformity. Similar conditions are found in north-central Texas where the Pennsylvanian-Permian boundary is placed in the midst of beds formerly classed as comprising the Cisco group. In parts of Trans-Pecos Texas, New Mexico, and other western States, a well-marked unconformity separates Permian rocks from older deposits.

All together, the Pennsylvanian formations of North America comprise a well established major stratigraphic division that is recognizable on structural, lithologic, and paleontologic grounds. The economic importance of Pennsylvanian strata has led to very detailed stratigraphic studies, both surface and subsurface, in numerous areas, although much of this work consists of very local investigations that give scant attention to stratigraphic classification or identification of regionally persistent rock units. The unfortunately restricted nature of such study, coupled with local nomenclatures adopted for many units, especially coal beds, adds a good deal of difficulty to the task of constructing a correlation chart. It is worthy of note that until recent years the prevalent view of geologists has been that almost all lithologic subdivisions of the Pennsylvanian are very limited areally. Present knowledge demonstrates that very many thin stratigraphic units are traceable for distances of hundreds of miles. Striking variations do occur, especially in nonmarine deposits and a multitude of unsolved or incompletely solved problems of correlation confront the stratigrapher working on Pennsylvanian rocks of North America, but it is proper to emphasize the large number of firmly established key horizons and precise equivalences of selected units in different areas.

CLASSIFICATORY STATUS OF PENNSYLVANIAN ROCKS

As originally proposed (Williams, 1891, p. 83), the Pennsylvanian rocks were classed as a series belonging to the Carboniferous system, and in this manner they have been consistently treated by many American geologists and by such official agencies as the United States Geological Survey. In 1906, Chamberlin and Salisbury (p. 539) advocated recognition of the Pennsylvanian rocks as an independent geologic system. Gradually, the considerations that support classification as a system, rather than a series, have been accepted as valid by so many American geologists that only a small minority now designate these rocks as a series. Included in the minority are the United States Geological Survey, some State geological surveys, authors of a

few textbooks and scientific papers, and others. Cogent arguments can be advanced opposing recognition of the Pennsylvanian as a system. Nevertheless, the subdivision of the North American geologic column that has been made the basis for designating subcommittees of the National Research Council Committee on Stratigraphy assigns to the Pennsylvanian chart a status equal with charts for the Cambrian, Ordovician, Silurian, Devonian, and other divisions that are nearly universally recognized as systemic. Thus, by implication the Pennsylvanian rocks are classed as a system. Major subdivisions of these rocks have been designated as series on the chart, although many geologists may prefer to employ another classificatory stratigraphic term.

Judgment of the proper stratigraphic classification of the Pennsylvanian rocks as a whole is not unanimous among members of the Pennsylvanian subcommittee, but analysis of this question has not been a primary objective of the study. There is agreement that the Pennsylvanian rocks comprise a very important, distinctive, and stratigraphically well defined segment of the American geologic column.

MAJOR DIVISIONS OF THE PENNSYLVANIAN ROCKS

The type section of the Pennsylvanian rocks, as inferred from the name, is located in Pennsylvania, although most students agree that a better standard section in the Appalachian region is revealed in West Virginia. In any case, the main divisions of Pennsylvanian rocks in the eastern United States have been established for decades on the basis of stratigraphic segments defined in Pennsylvania. In upward order, these are called Pottsville, Allegheny, Conemaugh, and Monongahela. Originally, other names were used, as Millstone grit, Lower Productive coal measures, Lower Barren coal measures, and Upper Productive coal measures. The Pottsville strata are named from exposures in the northeastern Pennsylvania anthracite coal district, and the others from localities in the western Pennsylvania bituminous coal area. The boundary between Pottsville and Allegheny strata has been fixed only by correlations between the anthracite and bituminous coal districts, and there are uncertainties in this correlation. In western Pennsylvania and throughout the Appalachian region generally, the boundaries between main divisions of the Pennsylvanian rocks have been defined in terms of somewhat arbitrarily selected coal beds. The base of the Allegheny beds has been drawn at the base of the Brookville coal; the base of the Conemaugh is placed at the top of the Freeport coal; and the base of the Monongahela is fixed at the base of the Pittsburgh coal. Each of these boundaries seems to be at a horizon where the strata immediately below and above the contact are entirely conformable. On the other hand, these boundaries fairly well separate groups of beds having persistent lithologic distinctions and containing more or less well-defined fossil floras of distinguishable aspect. Thus, the divisions have been found useful in describing and correlating Pennsylvanian deposits in at least the northern part of the Appalachian area. They may approximate naturally differentiated time-rock divisions, such as series or subseries (stage), but, insofar as the boundaries are placed arbitrarily at horizons other than unconformable surfaces that represent significant hiatuses in the stratigraphic record, they are not acceptable as

time-rock units having prospective widespread usefulness in partition of Pennsylvanian deposits of other regions.

The correlation chart sets forth five main stratigraphic divisions in the Appalachian region. The rocks that have been called Pottsville are divided in two so-called series, for which the names Lee (below) and Kanawha (above) are used. The Lee deposits correspond approximately to the Pocahontas and New River groups, and the Kanawha is equivalent to most of the Kanawha group as defined in some areas, although not in others. The Allegheny beds, which are designated as a series on the chart, are treated as extending downward to the base of the Homewood sandstone (slightly below the Brookville coal) and upward to the top of the Freeport coal, which has long been recognized as the Allegheny-Conemaugh boundary. The Conemaugh series is treated as previously defined. The top of the Monongahela series is drawn at the base of the Waynesville sandstone. Attention is directed to variations in previous placement of the boundaries of main divisions of the Pennsylvanian rocks in different parts of the Appalachian region, as is shown by the chart.

Pennsylvanian rocks of the Midcontinent region are divisible into at least five major parts having significance as time-rock units. These are definable throughout a wide area in the central and western parts of North America and are thought to be applicable to the eastern United States and Canada also. The Midcontinent and western Pennsylvanian deposits are generally characterized by importance of intercalated marine deposits. At horizons that mark boundaries between seemingly significant faunal and floral zones there are disconformities, which locally are very prominent but which generally are obscure. Interruption of sedimentation, accompanied in some geosynclinal areas by strong deformation and much erosion, is associated with the observed paleontologic changes, and this evidence defines natural time-rock stratigraphic units of importance. In upward order, the Midcontinent time-rock divisions are designated as Morrowan, Lampasan, Desmoinesian, Missourian, and Virgilian. The boundaries between these units are shown by heavy full lines in columns for the central part of the United States and by dotted lines in other areas.

CRITERIA FOR CORRELATION

GENERAL STATEMENT

Brief statement of the types of evidence used in correlating Pennsylvanian beds, as presented in the correlation chart is pertinent. Generally speaking, criteria for stratigraphic correlation are the same, whatever the age of the rocks concerned, but the nature of the available evidence and the degree of dependence on different types of evidence may vary considerably.

PHYSICAL CONTINUITY OF STRATIGRAPHIC UNITS

A considerable body of knowledge concerning the identity of differently named stratigraphic units among Pennsylvanian deposits of North America is established by determining physical continuity and equivalence of the elements concerned. This has been done both by detailed surface mapping and by tracing readily identified

units in more or less closely spaced borings or mine shafts. Many areas have been subjected to intensive stratigraphic study, and much definite information that bears on correlation of Pennsylvanian rocks now supplants former vagueness or complete ignorance. Numerous additions to present knowledge are promised by future work based on determination of continuity of beds. Most stratigraphic elements among Pennsylvanian deposits, such as a coal bed, under-clay, limestone stratum, or bed of black fissile marine shale, are persistent over considerable areas and are interpretable as unusually precise chronological and sedimentational indicators.

CYCLIC SEDIMENTATION

The phenomena of regularly oscillating conditions of sedimentation in which a succession of environments may be seen to have existed in constant order, many times repeated in the same area, especially characterize Pennsylvanian deposits. These cyclic successions are observable both in marine and nonmarine strata. They are most strikingly shown in sections of paralic deposits consisting of alternating marine and nonmarine layers. Recognition of the attributes of cyclic sedimentation has contributed greatly to precision of stratigraphic work in many Pennsylvanian areas and to definiteness of correlations. Conversely, the fidelity of repetition of various sorts of beds that may be produced by cyclic sedimentation adds to difficulty when positively identified key horizons are lacking. Gross errors of correlation have been made under these circumstances. Commonly it is important to study and compare sequences of beds rather than individual layers, but distinctive horizons having readily identified peculiarities of lithology, fossil content, or other character are valuable keys that may guide correlation.

SIGNIFICANCE OF UNCONFORMITIES

Pennsylvanian deposits of most areas are characterized by the common occurrence of hiatuses. A majority of these are classifiable as diastems having little significance, inasmuch as the time value of interrupted sedimentation seems to be small. Disconformities showing clearly marked evidence of erosion, such as sand-filled channels cut deeply into evenly stratified layers, are seen in many Pennsylvanian sections. These clearly denote both interruption of sedimentation and removal of previously formed deposits. The time value of the disconformities may be relatively large or small. Angular unconformities occur in some areas of Pennsylvanian rocks and these signify deformation of older strata at some time antecedent to renewal of sedimentation. All these breaks in the stratigraphic succession call for careful scrutiny in the classification and correlation of Pennsylvanian rocks.

Interruptions of sedimentation, if sufficiently prolonged, are important punctuation points in stratigraphic division of the Pennsylvanian deposits, whether or not these interruptions are locally marked by evidence of associated erosion. Deformation of beds during a break in sedimentation may have much historical significance, thus having definite bearing on classification and correlation, but equally important or more important breaks may be represented by obscure disconformities. The chief criteria for differentiating stratigraphically important unconformities from those

that are relatively unimportant are the definiteness and magnitude of paleontologic changes coinciding with the break, and the regional extent of the break. Some unconformities in Pennsylvanian rocks that generally are obscure are believed to indicate relatively long interruption of sedimentation, whereas other unconformities that locally are prominent seem to record unimportant incidents in the building of Pennsylvanian deposits.

FLORAL ZONES

Value.—Continental deposits of Pennsylvanian age, from oldest to youngest, have yielded fossil plants in many places. Such paleobotanical evidence is valuable for classification and correlation. Although some of the plant remains are rare, poorly preserved, and highly fragmentary, a multitude of excellent material furnishes basis for zonation. Studies by White, Read, Darrah, Bell, Noé, and others have defined the nature of successive Pennsylvanian floras, but much additional work in stratigraphic paleobotany remains to be done. The fossil plant zones indicated on the correlation chart are defined by Read. Since he could not prepare a discussion, the following brief summary describing features of the zones has been undertaken by Moore.

Zone of Neuropteris pocahontas *and* Mariopteris eremopteroides.—The lowermost Pottsville and equivalent deposits are characterized by the *Nauropteris pocohontas* flora. *N. pocohontas* is closely similar to *N. schlehani*, which is one of the guide fossils of middle and upper Namurian and lower Westphalian (zone A) deposits in northwestern Europe. Associated with *N. pocohontas* in the Appalachian region are *Mariopteris eremopteroides*, *Sphenopteris asplenioides*, and *Lyginopteris hoeninghausi*. This zone is correlated approximately with British strata containing Emily Dix's (1937) Flora B and with beds in northern France assigned to the zone of *Pecopteris aspera*. Strata of equivalent or possibly somewhat greater age in the eastern Canadian coal basins are especially distinguished, according to Bell, by *Sphenopteridium dawsoni* and *Mesocalamites cistiiformis*. The lowest Pennsylvanian (?) rocks of Nova Scotia (Canso group) are correlated by Bell with European beds containing the Flora A of Dix, which may include strata of Chesterian age (*Eumorphoceras* zone).

Zone of Mariopteris pottsvillea *and* Aneimites.—Beds associated with the Sewell coal in the south-central Appalachians and equivalent strata in other districts yield a rich flora that contains *Neuropteris schlehani*, *N. smithsii*, *N. gigantea*, *Mariopteris pottsvillea*, *M. acuta*, and *Aneimites* sp. This zone is correlated with uppermost Namurian (zone C) and lowest Westphalian (zone A) strata that are included in the European zone of *Neuropteris schlehani*. According to David White, this floral zone, which is well represented in the type Morrowan section of northwestern Arkansas, is one of the most readily differentiated in the North American succession.

Zone of Mariopteris pygmaea.—Upper Lee or New River beds in the Appalachian district are assigned to a zone characterized by prominence of *Mariopteris pygmaea*, associated with *M. acuta*, *Neuropteris rectinervis*, *N. gigantea*, *Linopteris obliqua*, and other plants. *Whittleseya desiderata*, *N. smithsii*, and *M. acuta* occur in this zone in eastern Canada. The boundary between the zone of *Mariopteris pygmaea* and the underlying zone of *M. pottsvillea* seems to be rather arbitrarily defined. Equivalent

deposits in northwestern Europe are thought to be those included in the Westphalian A zone, which is marked by *N. heterophylla*, *N. gigantea*, *Linopteris obliqua*, and *Alethopteris lonchitica*.

Zone of Cannophyllites *and* Neuropteris tenuifolia.—Upper Pottsville or Kanawha strata lying below the horizon of the Homewood sandstone are designated as belonging to the zone of *Cannophyllites*, including beds below the Quakertown coal horizon, and the zone of *Neuropteris tenuifolia*. Also recorded from these beds are *N. gigantea*, *N. missouriensis*, *Linopteris obliqua*, *Mariopteris muricata*, *Alethopteris grandifolia*, and *Eremopteris* sp. European deposits of equivalent age are grouped in the Westphalian B zone, which is also characterized by *N. tenuifolia*. This zone is marked by disappearance of neuropterids of the *N. schlehani* type.

Zone of Neuropteris rarinervis.—The uppermost Pottsville rocks of the type region, which are correlated with Alleghenyan strata below the Lower Kittanning coal, are included in the zone of *Neuropteris rarinervis*. Plants from lower horizons, such as *N. missouriensis*, *Linopteris obliqua*, *Alethopteris lonchitica*, and *Sphenophyllum fasciculatum*, also occur here, but attention is directed to the presence of new forms that characterize these and higher beds. Precursors of the upper Alleghenyan flora include plants identified as *N. scheuchzeri*, *A. sullivanti*, and *Pecopteris pseudovestita*. The zone of *N. rarinervis* is defined as the Westphalian C zone in northwestern Europe.

Zone of Pecopteris *and* Neuropteris flexuosa.—Upper Alleghenyan strata and most of the Conemaughan deposits are grouped in the zone of *Pecopteris* and *Neuropteris flexuosa*. Pecopterids become especially abundant in the upper part of the Alleghenyan and they persist to the close of the Pennsylvanian. Dominant species of this flora are *P. vestita*, *P. lamuriana*, *P. arborescens*, *Alethopteris serlii*, *A. grandini*, *N. flexuosa*, *N. ovata*, *Lescuropteris moorii*, *Mixoneura neuropteroides*, *Sphenophyllum emarginatum*, *S. oblongifolium*, and *Sigillaria brardii*. Most of these plants persist to the horizon of the Ames limestone but are rare or absent higher. This zone is correlated with the zones of *N. flexuosa*, Westphalian D, and *Pecopteris lamurensis*, lower Stephanian, in western Europe.

Zone of Lescuropteris.—The upper Conemaughan and lower Monongahelan beds are characterized by *Lescuropteris* and the so-called *Pecopteris polymorpha-Alethopteris grandini* assemblage of plants. Characteristic of this zone are *P. feminaeformis*, *A. magna*, *Odontopteris reichii*, and *Walchia* closely related to *W. piniformis*. This zone is considered to be Stephanian.

Zone of Odontopteris *and* Danaeites.—This zone comprises most of the Monongahelan of eastern States and equivalent rocks. The flora is like that of the zone of *Lescuropteris*, but new forms, such as *Taeniopteris jejunata*, *Odontopteris genuina*, *Sphenopteris multisecta*, and *Pecopteris truncata*, make appearance. *Lescuropteris* disappears in the upper Monongahelan.

FAUNAL ZONES

Value.—Marine fossils are very abundant in many Pennsylvanian strata, and commonly they are well preserved. Brackish-water shells occur somewhat rarely. Zonation of the Pennsylvanian deposits in terms of these remains is certainly possible,

but for many years it has been evident that the stratigraphic paleontologist engaged in study of Pennsylvanian faunas must distinguish forms from different horizons much more carefully than was done in early work. A number of fossils, such as *Mesolobus* among the brachiopods, *Prismopora* among the bryozoans, *Stereobrachicrinus* among the crinoids, the *Striatopora* ("*Pachypora*") and *Chaetetes* among the corals, are distinguishable at a glance from all other Pennsylvanian organisms, and in the Pennsylvanian they are restricted to a certain subdivision. They are useful zone fossils, but most remains of marine life in these rocks seem to represent very long-ranging organisms. These have little stratigraphic value until further work shows that the loosely defined "species" of generalized outline actually comprises a number of recognizable forms having narrow stratigraphic ranges. Thus, all Pennsylvanian fusulinids and most of those from Permian rocks formerly were identified as belonging to the European species called *Fusulina cylindrica*, whereas these are now recognized as belonging to several different genera and scores of species.

Brief notation of recognized faunal zones of the Pennsylvanian of North America is given in following paragraphs. Evidence from invertebrate paleontology has been used as completely as possible in constructing the Pennsylvanian chart.

Zonation based on fusulinids.—Except in near-shore habitats (that commonly are characterized by a molluscan assemblage or a biota composed chiefly of brachiopods, bryozoans, and mollusks), fusulinids are very common and widespread in marine Pennsylvanian faunas of North America; they are not common in the Western United States, however. They show evolutionary changes that are valuable aids in stratigraphic zonation and ordinarily they are so abundant that good specimens are easily obtained.

Beds of Morrowan age have been thought to be lacking in fusulinid remains, but Thompson (1942, p. 29) has reported primitive representatives of this group of fossils from the type Morrow section in northwestern Arkansas. The observed forms, allied to *Fusiella*, have not yet been described.

Deposits of Lampasan age have yielded very small fusulines of primitive structure in Texas, Oklahoma, Illinois, and Ohio. These include *Staffella* (*Pseudostaffella* of Thompson), the ancestral stem form of the family. This minute, subspherical genus is conservative and long ranging and reappears at various horizons far up into the Permian. The genus *Millerella* is a minute discoidal offshoot which appears in the Lampasan (Marble Falls in the old broad sense) of West Texas. But the normal, fusiform species are the dominant fusulines of this zone, and all belong to the genera *Fusiella* and *Fusulinella*. In the Lampasan series these are invariably small (less than 5 mm. in length and 2 mm. in diameter). Generally but a single species occurs in any horizon. The small size, primitive structure, and limited variation in size and form all indicate early stages of fusuline evolution. Since the genus *Fusulinella* overwhelmingly predominates in this series and nearly all of its known American species are found here, the Lampasan series may be characterized as the zone of *Fusulinella*. *Fusulinella prolifica* from the lower part of the Atoka in Oklahoma is similar to, but smaller than, *F. llanoensis* from central Texas, but both are structurally more advanced than *F. fittsi* of the basal Atoka. *Fusulinella iowensis* marks a well-defined subzone across Iowa and Illinois into Ohio, occurring in a zone in the

Cherokee shale of Iowa 90 feet below the White Breast coal, in the Seville limestone of Illinois, and in the Mercer limestone of Ohio. *Fusiella primaeva* occurs in central Texas somewhat below *Fusulinella llanoensis*, and a similar, if not identical, species occurs in West Texas and New Mexico.

Desmoinesian deposits are characterized by the genus *Fusulina s. s.*, which occurs in great abundance at many horizons and is represented by a considerable number of species. All species of this genus now known in America are confined to this series which therefore constitutes a well-defined zone of *Fusulina*.

Distinct evolutionary changes within this genus permit recognition of subzones. In the lower part, the species are all small and somewhat transitional between *Fusulinella* and *Fusulina*. Such forms are *Fusulina serotina* from the Putnam Hill limestone of Ohio, which Thompson described as *Fusulinella* but Dunbar assigns to *Fusulina; Fusulina pumilla* of the Seahorne limestone of Iowa and Illinois; and *F. leei* of the Curlew limestone of Illinois and equivalent or near-equivalent beds in Iowa and Oklahoma. This may be termed the subzone of *Fusulina leei*.

A broad subzone in the middle and lower middle part of the Desmoinesian is characterized by generally small species of *Fusulina* associated with species of the genus *Wedekindellina*. The most widespread species is *W. euthysepta* which ranges upward from the Stonefort limestone into the Oak Grove limestone in Illinois and appears also in the Seahorne formation of Iowa. Accordingly, this subzone may be designated as the subzone of *Wedekindellina euthysepta*. A similar species, *W. henbesti*, occurs just above the Bluejacket sandstone in Oklahoma. Either *W. euthysepta* or closely similar forms occur in the Kickapoo limestone of central Texas, a corresponding horizon in Trans-Pecos Texas, at various horizons ranging through the Armendaris group of New Mexico, in the Hermosa and McCoy formation of Colorado, and in the Quadrant formation in Wyoming.

The upper part of the Desmoinesian, consisting of the Marmaton group of Kansas and its equivalents, lies above the subzone of *Wedekindellina* and is characterized by numerous species of *Fusulina*, most of which are larger than those of the lower subzones. This zone may be further subdivided. The lower part (corresponding with the Fort Scott limestones of Kansas and the St. David, Herrin and Bankston Fork limestones of Illinois) is marked by rather short and highly inflated species, *F. girtyi, F. illinoisensis*, and *F. haworthi*. This is the subzone of *F. girtyi*.

The succeeding subzone is marked by a congenerie of elongate species, several of which attain exceptionally large size for this genus (*Fusulina piasaensis, F. mystiensis, and F. megista*) and some of which are almost subcylindrical (*F. eximia* and *F. lonsdalensis*). Here also occur small species, such as *F. acme* of Illinois and *F. inconspicua* of the Wewoka formation in Oklahoma. All of these late species are characterized by strong and regular septal folds and by a reduction of the chomata to low, narrow ridges. This may be called the subzone of *F. eximia*. In Texas it is represented in the Capps limestone, which carries a species very similar to, if not identical with, *F. acme*. In New Mexico the Bolander group carries species of this subzone.

The Missourian series is characterized by species of the genus *Triticites* and by the absence of *Fusulina*. The boundary between the Desmoinesian and Missourian

series is the most sharply defined and easily located datum surface in the Pennsylvanian system. The discovery by Newell and Keroher of *Wedekindellina* (or *Waeringella*, according to Thompson) *ultimata* in a thin bed near the base of the series in eastern Kansas marks an unexpected recurrence of that genus. With the exception of this species, and of species of *Staffella*, all of the fusulines of the Missourian series belong to the genus *Triticites*. The latter genus continues up through the Virgilian series where it completely dominates the fusuline faunas, but the various species fall into form groups representing stages of evolution that permit recognition of several subzones.

The lower portion of the Missourian series, including the Bronson and Kansas City groups and their equivalents, are characterized by species of the *Triticites irregularis* group. There are probably several distinguishable varieties or species, but all are characterized by rather small size, extremely slender, subcylindrical shape, thin wall, shallow septal folding, and fine alveolar wall texture. *T. ohioensis* is a well-defined example of this group that marks a zone from Ohio westward across Illinois including the Brush Creek and Cambridge limestones of Ohio and western Pennsylvania, the Livingston and Omega limestones of Illinois and the Livingston limestone of Indiana. It may not be distinct from the form described as *T. irregularis* from the Winterset limestone of Iowa. This fauna also marks a zone between conglomerate beds 4 and 5 in the Gaptank formation of west Texas. Other small slender species (such as *T. nebraskensis* of Iowa and the northern Midcontinent and *T. venustus* of Illinois) occur in this subzone, but they share the primitive characters of *T. irregularis*. Such slender species continue upward or recur locally higher in the Missourian series and in the Douglas group at the base of the Virgilian series, but above the Kansas City group they are overshadowed by larger species of the group of *T. secalicus*. Hence, the Bronson and Kansas City groups of the Midcontinent region may be distinguished as the subzone of *Triticites irregularis*.

In the Virgilian series the species of *Triticites* tend to assume a more inflated, fusiform shape, and in the higher beds to increase greatly in size. In the middle part of the Virgilian series (Lecompton to Burlingame limestones) *T. cullomensis* and its varieties predominate throughout the northern Midcontinent region. These strata may be termed the subzone of *Triticites cullomensis*. This species occurs in the Ames limestone of Pennsylvania and eastern Ohio and a similar species, *T. turgidus*, occurs in the Shumway limestone of Illinois. *T. cullomensis*, or a very similar form, is also common in the upper half of the Graham group of central Texas. A less common but more striking species of this subzone is *T. plummeri*, which is almost spherical and has a very small proloculum and rather strongly folded septa. It occurs in the Oread and Deer Creek limestones of the northern Midcontinent region and in the South Bend shale of central Texas, ranging up into the Breckenridge limestone.

Although conservative, medium-sized, fusiform species similar to *Triticites cullomensis* continue upward to the top of the Virgilian series, they are generally overshadowed in these higher beds by much larger, thickly fusiform shells of the type of *T. ventricosus*, which range up into the base of the Permian. This is the subzone of *Triticites ventricosus*. Such large species first appear in Kansas and Nebraska in the

Wakarusa limestone, and they are very striking in the Tarkio limestone in Kansas, Nebraska, Missouri, and Iowa. A similar large species, *T. callosus*, occurs in the Greenup limestone of Illinois. From the Fresnal group (upper "Magdalena") of New Mexico, Needham has described three large forms, *T. ventricosus* and its variety *sacramentoensis*, and *T. rhodesi*. According to Thompson, the genus *Dunbarinella* makes its appearance in the Deer Creek limestone, near the middle of the Virgilian series, and ranges upward into the Permian.

Zonation based on sponges.—Remains of sponges are very abundant in many Pennsylvanian marine strata, and at least within the limits of moderate-sized areas, such as the Illinois-Indiana basin or the northern Midcontinent region, these fossils have definite value in paleontologic correlation. The Marble Falls limestone and various other Early Pennsylvanian rocks are distinguished by the presence of very numerous siliceous sponge spicules. Desmoinesian, Missourian, and Virgilian strata at several horizons contain distinctive species of sponges belonging to *Amblysiphonella*, *Wewokella*, *Maeandrostia*, *Heliospongia*, *Girtycoelia*, and other genera, which have limited vertical distribution and considerable horizontal spread. Some stratigraphic units, notably in the Lansing group of Kansas and lower Canyon of Texas, bear these fossils in extraordinary profusion. A zonation of the Pennsylvanian rocks based on distribution of sponges is only partly practicable, because of limitation of knowledge.

Zonation based on corals.—Until recently, only a few species of Pennsylvanian corals have been described. Inasmuch as specimens of widely different age have commonly been referred to one or another of these few forms, it has been presumed that the Pennsylvanian corals have exceptionally long range and that they have little value for zonation or correlation. Actually there are many distinguishable corals.

Morrowan and Lampasan marine strata of the Midcontinent region are characterized by the presence of numerous species of corals that are unknown in older or younger rocks. Moore and Jeffords (1944) have described more than 50 species, many of which belong to previously undescribed genera. The coral fauna of Early Pennsylvanian rocks on the southwest flank of the Ozarks corresponds to that observed in equivalent deposits on the borders of the Llano uplift, and at least one diagnostic Morrowan species, *Striatopora oklahomensis*, has been collected from basal Magdalena limestone in southern New Mexico. Colonies of *Chaetetes* that are common in some Morrowan and Lampasan rocks of Arkansas, Oklahoma, and Texas are specifically distinct from the so-called *C. milleporaceus*, which is very common in Desmoinesian deposits.

Numerous corals, mainly undescribed, are found in beds of Desmoinesian age. Most common are species of *Lophophyllidium*. The unconformity at the base of the Missourian series marks the upper limit of known occurrence of *Chaetetes* in the Pennsylvanian of North America. The species *C. milleporaceus*, described from central Russia, is probably distinct from the widespread American form commonly referred to this name. As a matter of fact, studies indicate that at least two species of Desmoinesian *Chaetetes* can be recognized. Some corals, though highly distinctive, like "*Trachypora*" *prosseri*, are so restricted geographically that they lack value for stratigraphic correlation.

Some Missourian and Virgilian marine deposits are rich in fossil corals. The Beil

limestone member of the Lecompton limestone (Shawnee), for example, almost everywhere carries large numbers of *Caninia torquia*, *Syringopora multattenuata*, *Aulopora*, and other corals. *Lophophyllidium* is represented by numerous species in post-Desmoinesian formations. Determination of the stratigraphic usefulness of these fossils requires studies not yet made, although Jeffords has already done considerable work.

Zonation based on crinoids.—Remains of crinoids, generally fragmentary, are very common in many Pennsylvanian marine rocks, and study of them promises to contribute valuable data for stratigraphic zonation and correlation. A large number of genera and species, mostly dicyclic inadunates, is known, but there are many undescribed forms.

Rocks of Morrowan age contain a varied crinoid fauna of distinctive aspect. This assemblage contains no Chesterian species, and no Morrowan species are known to range into younger Pennsylvanian rocks. Most crinoid genera of Morrowan age range upward but not downward. Curiously, several of these genera are known only from supposed Permian rocks of Timor (Netherlands East Indies) and Morrowan deposits of Arkansas and Oklahoma. Diagnostic crinoids belonging to this lower Pennsylvanian zone include *Allocatillocrinus rotundus*, *Ethelocrinus oklahomensis*, *E. texasensis*, *Lasanocrinus daileyi*, *Paradelocrinus dubius*, *Diphuicrinus croneisi*, *Stereobrachicrinus pustullosus*, *Cibolocrinus tumidus*, *C. punctatus*, and *Brachial simus*.

Very few crinoids from strata of Lampasan age are now known, but there are numerous well-preserved specimens in Desmoinesian rocks. Among characteristic forms of the latter are *Delocrinus granulosus*, *Laudonocrinus catillus*, *Sciadiocrinus harrisae*, *Plaxocrinus mooresi*, *Galateacrinus stevensi*, *Pirasocrinus scotti*, and *Allagecrinus dignatus*. Distinctive genera, not known from older beds, that appear in Desmoinesian deposits and range upward are *Stellarocrinus*, and *Lecythiocrinus*.

Beds of Missourian age have yielded abundant crinoids, especially in the environs of Kansas City, in southeastern Kansas and northeastern Oklahoma, and in north-central Texas. Typical representatives of this upper middle Pennsylvanian assemblage, most of which have narrowly restricted vertical range, include *Delocrinus verus*, *D. missouriensis*, *D. subhemisphericus*, *D. pictus*, *Ethelocrinus magister*, *Parulocrinus compactus*, *Apographiocrinus exculptus*, *A. typicalis*, *Aesiocrinus magnificus*, *Oklahomacrinus loeblichi*, *Perimestocrinus impressus*, *Stellarocrinus geometricus*, *Paragassizocrinus tarri*, *Erisocrinus typus*, *Allagecrinus strimplei*, and *A. bassleri*.

Virgilian deposits are somewhat less rich in crinoids than older Pennsylvanian rocks, but species are known from horizons distributed from near the base to the top. Characteristic forms are *Delocrinus vulgatus*, *Plaxocrinus virginarius*, *Plummericrinus mcguirei*, *Stellarocrinus stillativus*, *Oklahomacrinus supinus*, and *Utharocrinus oreadensis*. *Allagecrinus*, *Ethelocrinus*, *Lecythiocrinus*, *Erisocrinus*, and various other common Pennsylvanian genera are present in Virgilian strata.

Zonation based on bryozoans.—Massive, ramose, encrusting, and fenestrate colonies of bryozoans belonging to 2 dozen or more genera are very common Pennsylvanian marine fossils. Like the corals, the bryozoans are undoubtedly useful for stratigraphic zonation, but much additional paleontologic study is needed. "Fistuliporoid" bryozoans, mostly assignable to the genus *Cyclopora*, are distributed through-

out the Pennsylvanian, as are the fenestrate forms, such as *Fenestrellina*, *Polypora*, and *Septopora*. Various species of these genera have restricted range. The genus *Prismopora*, distinguished by the triangular cross section of its branches, is restricted to pre-Missourian deposits. *Meekopora* and *Thamniscus* occur in pre-Pennsylvanian rocks but in the Pennsylvanian are common only in uppermost Virgilian beds.

Zonation based on brachiopods.—Most Pennsylvanian brachiopods are distinguished readily from Mississippian and Permian brachiopods, but most genera and species, as currently defined, have too great stratigraphic span for use in detailed paleontologic zonation.

Morrowan strata are distinguished from Upper Mississippian zones by the appearance of *Hustedia* and *Squamularia* and by the absence of true *Productus* ("*Diaphragmus*"). *Hustedia miseri* and *H. brentwoodensis*, which occur in Morrowan beds, differ from representatives of this genus, commonly identified as *H. mormoni*, occurring in younger Pennsylvanian rocks. *Dictyoclostus morrowensis* is a fairly distinctive species of Morrowan and Lampasan age.

Strata assigned to the Lampasan series and beds of equivalent age contain Spirifers having simple nonfasciculate plications, like *Spirifer opimus*, *S. rockymontanus*, and *S. occidentalis*, but locally they also bear shells like *Neospirifer meusebachianus* having bundled plications of early type. *Marginifera* appears and is represented by *M. nana* and *M. haydenensis*, which seem not to range into Desmoinesian deposits. A very important brachiopod genus that ranges from upper Lampasan beds to the top of the Desmoinesian is *Mesolobus*. The species *M. striatus* is reported by Weller (personal communication) to be restricted to the Mercer, Kendrick, Dingess, Seville, and slightly older rocks, whereas *M. mesolobus* first appears in beds that here are classed as lower Desmoinesian.

The brachiopod fauna of Desmoinesian deposits resembles that of older Pennsylvanian horizons in the common occurrence of nonfasciculate Spirifers. These do not range into Missourian and younger strata, however. *Mesolobus* is abundant and very widespread. *Marginifera muricatina* and *M. missouriensis* are restricted to the Desmoinesian, but *M. splendens* ranges upward into the Missourian. Small specimens of *Squamularia perplexa* are extremely common in some Desmoinesian marine faunas, whereas shells referred to this species from younger rocks are larger, wider, and relatively uncommon.

Missourian brachiopods include several typical Neospirifers having strongly fasciculate plications. *Dictyoclostus*, *Juresania*, *Marginifera*, and *Linoproductus* are very common. *Chonetina* appears and is extremely abundant in some Kansas City and Lansing zones. The genus *Enteletes*, which ranges upward to the Permian, begins in upper Missourian rocks. Characteristic brachiopods of Missourian age include *Neospirifer latus*, *Linoproductus missouriensis*, *Echinoconchus semipunctatus*, *Enteletes hemiplicatus*, *Marginifera splendens*, *Chonetina flemingi plebeius*, and *Chonetes granulifer*.

Upper Pennsylvanian brachiopod faunas, as represented by Shawnee, Wabaunsee, and equivalent horizons, differ only slightly from Missourian assemblages. The chonetid genus *Lissochonetes* is not restricted to Virgilian deposits but is generally characteristic of them. *Enteletes* occurs throughout the series. Species that belong

essentially or wholly to Virgilian beds include *Marginifera wabashensis, M. hystricula, Chonetes transversalis, Dictyoclostus crassicostatus, Echinoconchus moorei, Krotovia meeki, Lissochonetes geinitzianus,* and *Neospirifer kansasensis.*

Zonation based on pelecypods.—Zonation of the European Upper Carboniferous in terms of brackish-water clams has been worked out, but neither brackish-water nor marine pelecypods have been much used as yet in differentiating Pennsylvanian faunal zones in North America. Careful study of these fossils, however, indicates that many of them are useful in stratigraphic paleontology. Recent work by Newell (1937; 1942), chiefly on two groups called Pectinacea and Mytilacea, indicates existence of numerous species having more or less restricted vertical range, and some of these are both abundant and widely distributed.

Few distinctive pelecypods are known from Morrowan strata. Newell reports *Aviculopecten halensis, Pseudomonotis precursor,* and *P. aurisculpta* from marine Morrowan beds in the Midcontinent region, and the brackish-water forms *Naiadites ohioensis* and *N. carbonaria* from strata of equivalent age in the Appalachian district. Bell reports that oldest Pennsylvanian rocks of the Acadian province are characterized by *Naiadites* of the *N. modiolaris* group, whereas these clams are absent in younger beds. *N. carbonaria* ranges upward into rocks of Desmoinesian age.

Kanawhan or Lampasan horizons are distinguished by *Fasciculoconcha scalaris, Limipecten morsei, Euchondria smithwickensis, Myalina copha, Volsellina subelliptica,* and *Septimyalina perattenuata,* although the last two forms range upward into Virgilian beds.

Pelecypods that are restricted to rocks of Desmoinesian age are fairly numerous. Some of the most common and important of these are *Dunbarella knighti, D. reclalaterarea, Aviculopecten germanus, A. flabellum, A. coxanus, A. mazonensis, Fasciculoconcha providencensis, Limipecten wewokanus, Streblochondria hertzeri, Euchondria pellucida, E. subcancellata, Selenimyalina dotti, Septimyalina quadrangularis, S. sinuosa, Myalina lepta, Myalinella cuneiformis, Orthomyalina ampla,* and *O. slocomi.* The last two range through the Missourian.

Characteristic Missourian pelecypods include the following species: *Aviculopecten gradicosta, A. occidentalis, A. exemplarius, Streblochondria sculptilis, S. stantonensis, Pseudomonotis robusta, P. sayrei, P. fredoniensis, Promytilus annosus, P. swallovi, Selenimyalina quadrata, S. meliniformis, Myalina arbala,* and *Lithophaga subelliptica.* Common forms in upper Missourian and Virgilian deposits are *Pterinopecten welleri, Pseudomonotis beedei, P. equistriata,* and *Myalina glossoidea.*

Virgilian index fossils among the pelecypods include *Dunbarella whitei, Aviculopecten moorei, A. basilicus, Limipecten texanus, Streblochondria condrai, Euchondria neglecta, Myalina petina, M. miopetina,* and *Promytilus priscus.* A well-known species that ranges from Virgilian into Lower Permian rocks of the Midcontinent area is *Orthomyalina subquadrata.*

Zonation based on gastropods.—Many species of Pennsylvanian gastropods have been described, but this group of fossils has not yet been employed effectively in stratigraphic correlation or zonation of Pennsylvanian rocks. Most important contributions to knowledge of this group in recent years are the work of J. Brookes Knight, but his papers are mainly devoted to the description and taxonomy of these fossils.

Reference is here made to one group of gastropods, the straparollids, which seem to have stratigraphic value. Undoubtedly there are others that are as widespread and useful as the straparollids. Knight (1934) has described and illustrated the following forms: *Euomphalus serratus*, from beds of Morrowan age; *Straparollus savagei*, from beds of Lampasan age; *E. reedsi*, *E. umbilicatus*, *E. hollingsworthi*, and *E. subsulcatus*, from beds of Desmoinesian age; *E. catilloides* and *E. plummeri*, from beds of Missourian age; and *E. subrugosus*, common in Virgilian beds but occurring also sparingly in older rocks.

Zonation based on cephalopods.—Nautiloids and ammonoids occur at many horizons in Pennsylvanian marine deposits, and these fossils, especially the ammonoids, are useful not only for correlation of widely separated outcrops in North America but for comparison of these with Upper Carboniferous cephalopod zones in other parts of the world. Studies chiefly by Plummer, Miller, Scott, and Furnish have added greatly to knowledge of American genera and species of Late Paleozoic cephalopods.

Morrowan rocks may be designated as belonging to the zone of *Gastrioceras* and *Branneroceras*, and this zone corresponds at least partly to the zone of *Gastrioceras* (or G zone) of the Upper Carboniferous in Great Britain. The genus *Reticuloceras*, which characterizes the R zone in northwestern Europe, just below the G zone, has not been recognized in North America. Deposits of the R zone are probably equivalent to oldest Pennsylvanian (Pocahontas, Jackfork-Stanley) formations in North America. Morrowan rocks in northwestern Arkansas contain *Gastrioceras kingi* and other species closely resembling the European *G. listeri*, as well as *Branneroceras* which is a derivative of *Gastrioceras*. *Pronorites arkansanus*, which is associated with *Branneroceras*, represents a wholly different ammonoid stock that continues into younger rocks.

Beds of Lampasan age may be designated as belonging to the zone of *Paralegoceras*. This is a distinctive genus having a laterally compressed form, moderately complex sutures, and showing a peculiar triangular juvenile coiling. Lower Atoka deposits in southern Oklahoma, Big Saline ("upper Marble Falls") limestone, and Smithwick shale in north-central Texas, and equivalent rocks in some other regions have yielded an ammonoid fauna that includes *Paralegoceras texanum*, *Pseudoparalegoceras compressum*, *Gastrioceras smithwickense*, *Glaphyrites raymondi*, *Nuculoceras smithwickense*, and *Diaboloceras varicostatum*.

Desmoinesian rocks are classed by A. K. Miller (personal communication) under the designation of zone of *Owenoceras* and *Wellerites*. Described ammonoids from this part of the Pennsylvanian have been collected mainly from horizons in the Cherokee shale of the northern Midcontinent region and the Millsap Lake group of Texas. Representative species include *Gastrioceras venatum*, *Glaphyrites angulatus*, *G. hyattianus*, *G. welleri*, *G. excelsus*, *Paralegoceras iowense*, *Pseudoparalegoceras brazoense*, *Dimorphoceras politum*, and the nautiloids *Brachycycloceras longulum*, *Metacoceras biseriatum*, and *Parametacoceras bellatulum*.

The Missourian series of the northern Midcontinent area and north-central Texas has yielded numerous ammonoids. These rocks may be grouped as belonging to the zone of *Eothalassoceras* and *Prouddenites*. Oldest known species of *Schistoceras*, *Paraschistoceras*, *Parashumardites*, and *Uddenites* are recorded from the Missourian. Characteristic species of this zone include *Eothalassoceras inexpectans*, *Schistoceras*

missouriense, S. hildrethi, Prouddenites bösei, P. primus, Daraelites texanus, Goniolobo-ceras gracellense, Gastrioceras illinoisense, G. subglobosum, G. modestum, Eoasianites kansasensis, E. millsi, Paraschistoceras reticulatum, Parashumardites fornicatus, P. senex, and *Marathonites parkeri.*

The upper main division of the Pennsylvanian rocks, of Virgilian age, is intermediate between Missourian and Permian as represented by its known cephalopods. Characteristic fossils of the *Uddenites schucherti* fauna near the base of the series in north-central Texas and in western Texas are *Schistoceras hyatti, S. diversecostatum, Gastrioceras modestum, Glaphyrites kansasensis, Shumardites simondsi,* and *Vidrioceras irregulare.*

Zonation based on trilobites.—Pygidia and, less commonly, other parts of trilobites are known from many Pennsylvanian formations. Well-preserved complete specimens are uncommon. Study by Weller, not yet completed, indicates that trilobite remains may be used to some extent in correlating Pennsylvanian strata. In Morrowan strata, according to Weller, are representatives of the genera *Paladin* and *Ditomopyge,* of which the former occurs also in Chesterian rocks and the latter ranges into the Permian. Described species of *Ditomopyge* seem to have more or less restricted range. The genus *Ameura* is reported from Desmoinesian to Lower Permian beds; fairly well known representatives of this genus are *A. sangamonensis* of Desmoinesian age and *A. major* from Missourian rocks.

Zonation based on ostracodes.—Numerous papers describing Pennsylvanian ostracodes have been published. A survey of this literature, undertaken by Knight as part of the Pennsylvanian Subcommittee's work, indicates that these fossils lack value for general zonation or interregional correlation. At any rate, they are insufficiently known to warrant other judgment. On the other hand, these microfossils are definitely useful in stratigraphic studies having limited geographic scope. Also, some Pennsylvanian strata, such as the Morrowan deposits of the Ozark region and southern Oklahoma, carry distinctive types of ostracodes that can be differentiated easily from other described forms; among these fossils are *Monoceratina ventralis, Kirkbya bendana,* and *Amphissites marginiferus.* Chalmer Cooper, now engaged in extensive work on Pennsylvanian ostracodes, thinks that these fossils promise to have real value for correlation of Pennsylvanian marine strata in different basins.

EVIDENCE FOR CORRELATIONS

ACADIAN PROVINCE

Nova Scotia and New Brunswick (Columns 1 to 4).—Classification and correlation of Pennsylvanian rocks in eastern Canada, as shown on the chart, are indicated by W. A. Bell.

Generally speaking, the stratigraphic units of the Pennsylvanian succession in Nova Scotia and New Brunswick have been compared most closely with divisions of the European Upper Carboniferous rocks, but they also correspond well with divisions recognized in the Pennsylvanian of the United States.

The lowest division, represented by the Canso group and correlatives occurring

in almost every one of the Acadian districts, is separated by an unconformity from succeeding deposits. This oldest Pennsylvanian division rests disconformably on Mississippian rocks that contain a fauna not younger than the D_2 zone (early Chesterian age) of the Avonian sequence in England. The Canso and equivalent strata contain the oldest known specimens of the brackish-water clam, *Anthracomya*, which is common in various Upper Carboniferous horizons of Europe. Diagnostic plant fossils of the zone of the Canso group are *Sphenopteridium dawsoni* and *Mesocalamites cistiiformis*. A few Mississippian plants, such as *Asterocalamites* and *Telanguim* (*T. affine*), range upward into the Canso beds, but no species extends into post-Canso deposits. This zone is lower Namurian in age, being correlated with the Namurian A zone, equivalent to the *Eumorphoceras* zone (E) and possibly part or all of the overlying *Homoceras* zone (H) in England. Lower Namurian deposits, which are definitely Chesterian in age, are included in the Upper Carboniferous of the Old World.

The Riversdale group and equivalent rocks of eastern Canada rest unconformably on Mississippian strata in some places and elsewhere on early Pennsylvanian (Canso). This second division of the Pennsylvanian contains the first observed clams of the *Naiadites modiolaris* group. Diagnostic plants of Riversdale age are *Neuropteris smithsii*, *Mariopteris acuta*, and *Whittleseya desiderata*. The first two of these are recorded also from the lower middle Pottsville (Morrowan) in the flora of the Sewell coal horizon, and *M. acuta* occurs also in the upper Lee or New River beds. These deposits of the Acadian region are correlated with upper Namurian and lower Westphalian zones characterized by *Neuropteris schlehani*, *N. heterophylla*, and *Alethopteris lonchitica*.

The Cumberland group and corresponding beds rest disconformably or nonconformably on the Riverdale equivalents or directly on strata of Canso age. Diagnostic fossils include *Sphenopteris valida* and broad-leaved *Samaropsis* of the *S. baileyi* group. The Cumberland deposits are correlated with the Westphalian B zone of Europe, which is characterized by *Neuropteris tenuifolia* and *Lonchopteris*. Upper Pottsville or Kanawha deposits of the Appalachian region and Atoka (Lampasan) beds of the Midcontinent region are correlatives.

The youngest known Pennsylvanian rocks of the Acadian province are assigned to the Pictou group and correlated beds. These deposits mark the first appearance of *Anthraconauta* of the *A. phillipsi* group and of numerous plants, including especially *Pecopteris*, *Ptychocarpus*, and *Acitheca*. Diagnostic forms from these beds include *Linopteris obliqua*, *Neuropteris rarinervis*, *N. scheuchzeri*, *Sphenopteris striata*, *Alethopteris serlii*, and *Sphenophyllum emarginatum*. These plants define the zone of *N. rarinervis* (Westphalian C) and the zone of *N. flexuosa* (Westphalian D) of the European section. In well-defined manner also, they indicate an Alleghenyan age. The upper part of the Pictou group contains the lowest known occurrence of *Sphenophyllum oblongifolium*, a plant of Conemaughan (or Missourian) age and younger.

Although divisions of the Pennsylvanian rocks of eastern Canada as indicated on the chart seem to correspond well to certain segments of geologic time, the term "series", used in earlier reports, has been discarded by the Geological Survey of

Canada in favor of "group", inasmuch as use of "series" is restricted to time-rock units having no geographic connotation.

APPALACHIAN REGION

Anthracite coal fields, northeastern Pennsylvania (Columns 6 and 7).—The nomenclature of beds in the southern and two middle anthracite coal fields is generally the same, but that of the northern field is distinct. The only fairly well established correlations between the southern and northern fields are those of the Buck Mountain coal (south) with the Red Ash coal (north), Mammoth coal (south) with the Baltimore coal (north), and Orchard coal (south) with the Orchard coal (north). These inferred equivalences are shown on the chart, and intervening beds are tentatively matched on the basis of their position. Placement of the coals in these columns is determined by correlation with beds in the bituminous coal area and by evidence of fossil floras.

The Lykens coal beds and associated strata, which are the oldest Pennsylvanian deposits in northeastern Pennsylvania, were closely studied by David White, and more recently they have been examined carefully by Read. Abundant fossil plants furnish evidence that the upper strata of this succession, near the horizon of Lykens coal No. 2, are not younger than the Sharon coal horizon of western Pennsylvania and the Sewell coal in southern West Virginia. Indeed, this is one of the most firmly fixed floral datums in the Pennsylvanian, and White and Read identify it with the horizon of the Sewanee coal of southern Tennessee and Georgia, the Battery Rock coal near the base of the Pennsylvanian in southern Illinois, and the Baldwin coal in the middle Morrowan of northwestern Arkansas. Read correlates the Lykens No. 4 coal with the Fire Creek coal of southern West Virginia and Virginia, and the Lykens Nos. 5 to 7 coals with the Pocahontas Nos. 2 to 4 coals in the south-central Appalachians. The Campbell's Ledge slate of the northern anthracite field, which attains a maximum thickness of about 5 feet, contains fossil plants considered to be of Mercer age.

Directly above the Campbell's Ledge slate is a prominent quartz-pebble conglomerate containing cobbles up to 6 inches in diameter. This deposit, well exposed near Pottsville where it is some 300 feet thick, is known as the Pottsville conglomerate or "Goose Egg" conglomerate. It contains no diagnostic fossils, but the overlying Buck Mountain coal, which is separated from the conglomerate by only a thin root-bearing clay bed, has a roof flora of Kittanning age. White placed the top of the Pottsville at the base of the Buck Mountain coal. Read believes that the "Goose Egg" conglomerate corresponds to lower Alleghenyan rocks of western Pennsylvania ranging from approximately Brookville to Lower Kittanning, and he thinks that this coarse conglomerate is separated by a considerable hiatus from the Lykens and Campbell's Ledge beds. Extensive studies of the stratigraphy and paleobotany of lower Pennsylvanian deposits in the Appalachian area have led Read to advocate revision of the Pottsville by removal of beds above the unconformity at the base of the "Goose Egg" conglomerate. According to such definition, the Pottsville of the type region would be represented only by the Lykens coals and associated plant-

bearing beds, and it would correspond almost precisely to the Pocahontas and New River groups of southern West Virginia and to Lee deposits of Virginia. Strata belonging between the top of the restricted Pottsville and base of the Alleghenyan series (base of Homewood sandstone and equivalents) correspond closely to the division called Beaver River by the Second Pennsylvania Geological Survey (base of Sharon sandstone to top of Homewood sandstone). Read suggests the fitness of Beaver River as a series name for Appalachian deposits that seem to embrace the same time span as those called Lampasan in the Midcontinent area. Ashley opposes this revision, preferring to use Beaver River in an expanded stratigraphic span that reaches from the base of the Sharon sandstone or conglomerate, below, to the base of the Lower Kittanning coal, above. Classifying the Beaver River group as upper Pottsville, Ashley draws the boundary between Pottsville and Alleghenyan at the base of the underclay below the Buck Mountain and Lower Kittanning coals,—that is, at the top of the zone of *Neuropteris rarinervis*.

Ashley (personal communication) contributes the following discussion:

"As to classification and boundaries of strata below the Buck Mountain-Lower Kittanning-No. 5 Block coal, there are the alternatives: (1) To draw boundaries strictly on a paleontologic basis, letting the lines fall where they may, even though this requires new nomenclature or readjustment of old boundaries; or (2) To make necessary adjustments of the boundaries and names but retain historic boundaries and names as far as possible. I favor the latter course because of advantage it offers to the field geologist or engineer. The old boundaries were drawn on prominent coal beds or other horizons that are easy to follow in the field and that have economic value when shown on a map. Thus, the Buck Mountain (Twin bed) coal has been mapped extensively as the lowest workable bed in the three lower anthracite fields. It will be mapped in future because of its economic importance. To draw the line between Lower and Upper Pennsylvanian 'somewhere in the plexus of uppermost conglomerates' where David White says the paleontologic boundary falls, is difficult in the field and has no economic value when accomplished.

"In the bituminous field of western Pennsylvania, the boundary between Pottsville and Allegheny has been drawn theoretically at a coal called Brookville, just above the Homewood sandstone. Evidence increases to show that the Brookville coal at Brookville is the stratigraphic equivalent of the Mercer coals of Mercer County. David White is authority for the statement that the paleontologic break comes not at the top of the Homewood sandstone but at the base of the Mercer group or top of the Connoquennessing sandstone. Unfortunately, the Homewood sandstone has proved to be a highly variable stratum, as though it represented a sand filling of old channels. Many sections show no sandstone at this horizon; in some it is very massive; and in others it is a shaly or thin-bedded sandstone. Consequently, detailed recent mapping has revealed many errors in its correlation and tracing. Coal beds below the Homewood are likewise variable, even more so than the sandstone, ranging from four or five beds distributed through 65 feet of section to a single bed about 6 feet thick. Mistakes in previous correlation of these beds is mute evidence of their low value in defining an important boundary.

"The boundary between Lower and Upper Pennsylvanian, according to my suggestion, should be drawn at the horizon of the Buck Mountain, Lower Kittanning, and No. 5 Block coals. The following considerations support this proposal. (1) The horizon is important in mapping in view of its economic importance. (2) In large areas it marks the economic boundary between persistent, widely workable coals and clays, above, and more irregular, less persistent, less widely workable coals and clays, below. This is true not only in the Appalachian area but in the Midcontinent, assuming that the Lower Kittanning and equivalent eastern coals are correlated rightly with the No. 2 coal of Illinois and the Bevier coal of Missouri. In southern West Virginia, conditions are reversed from those just stated, inasmuch as No. 5 Block coal marks the top of the workable coals. In northern West Virginia, the black flint helps to identify the No. 5 Block, just as the Vanport limestone aids in distinguishing the Lower Kittanning throughout a large area in western Pennsylvania. (3) Although the floras of two stratigraphically distant parts of the section are strikingly different, the transition between them is rather gradual and, accordingly, difficult to define and map. Thus, in the type Pottsville area, the Lower and Upper Lykens Valley divisions of David White are very distinct, but between them is an 'intermediate' transitional zone having a thickness of 130 feet or more. Also, at the top is an upper intermediate division where even White could draw no precise boundary. In his study of the Kanawha section, White (1900) reveals a clear distinction between lower and upper Kanawha beds, although the line separating them is drawn 'somewhere in the 300 feet of barren

interval'. One may grant that floras have great value for indication of broad correlations in the coal measures, but plant fossils commonly do not lend themselves to definition of exact boundaries that can be identified readily in rock sections and represented on a map.

"If identifiable thin limestone or coal beds, rather than fossil plants, are employed to define boundaries, how shall Lower Pennsylvanian rocks be subdivided and how shall these subdivisions be bounded? In the Appalachian region, and possibly also the Eastern Interior, I propose to divide the Pennsylvanian system into two series: the Pottsville, below, and the Pittsburgh, above. The boundary between these series is drawn at the base of the underclay lying below the Buck Mountain, Lower Kittanning, and equivalent coals.

"Main divisions of the Pottsville seemingly should be based on study of the thickest section, assuming that increased thickness is due to the presence of elements lacking elsewhere. Southern West Virginia seems to be the proper place for such study and from this region the following divisions of the Pottsville are proposed, named in upward order.

"*Pottsville A* (Pocahontas group of Appalachian province), extending from the base of the Pennsylvanian to the top of the Beckley coal and equivalents, such as the Lykens Valley No. 5 coal of the southern anthracite region. This division, which is characterized by *Neuropteris pocahontas*, is approximately equivalent to the Pushmataha strata of the Ouachita region and to the Namurian B zone of the European section.

"*Pottsville B* (Lower New River of Appalachian province), including strata from the top of the Beckley coal to the base of the Sewell coal or its underclay. The upper boundary is also marked by the Lykens Valley No. 3 coal, Bed H of the Pottsville section, the Sharon coal of western Pennsylvania, and equivalent coals. This zone, characterized by *Mariopteris pottsvillea*, is nearly equal to the Namurian C zone of the European section.

Pottsville C (Upper New River of Appalachian province), extending from the base of the Sewell or Sharon coal to the base of the Upper Nuttall sandstone. In northeastern Pennsylvania this represents beds from the base of Lykens Valley No. 3 coal to that of No. 1 coal, or to Bed L of the Pottsville section, and in western Pennsylvania to the base of the Lower Connoquennessing sandstone. This zone is characterized by *Mariopteris pygmaea* and is correlated with strata of Namurian C and Westphalian A in Europe.

"*Pottsville D* (Lower Kanawha of Appalachian province), comprising deposits from the base of the Upper Nuttall sandstone to the base of the Campbells Creek coal or top of the Upper Connoquennessing sandstone. This division, approximately equivalent to Midcontinent Lampasas beds and Westphalian B strata of Europe, is marked by *Cannophyllites* and *Neuropteris tenuifolia*.

"*Pottsville E* (Upper Kanawha of Appalachian province), reaching from the top of the Upper Connoquennessing sandstone or base of underclay beneath the Lower Mercer coal to the base of the Lower Kittanning, Buck Mountain, or Block No. 5 underclay. This corresponds to the Clarion member of the Allegheny of some authors and is equivalent to most of the lower Des Moines or Cherokee shale in the Midcontinent area. It is characterized by *Neuropteris rarinervis* and is considered to represent most, if not all, of the Westphalian C zone in Europe.

"The Allegheny group is desirably re-defined to extend from the top of Pottsville E division to the top of the Upper Freeport or E coal. The Conemaugh and Monongahela groups are not modified."

As shown on the chart, the boundary between the Alleghenyan and Conemaughan series in the anthracite fields is tentatively drawn at the top of the Baltimore and Mammoth coals. This is based on correlation of these coals with the Upper Freeport coal of western Pennsylvania, which defines the boundary in that region.

The Mill Creek limestone, in the upper part of the northern field section, contains marine fossils. It is correlated with the Ames limestone, the highest marine limestone in the bituminous coal field area of Pennsylvania. This correlation and that of the coals in the upper part of the anthracite fields are made by Wanless.

Southwestern Pennsylvania and Maryland (*Column 8*).—This column is based on reports of the Pennsylvania Geological Survey, especially on work by Ashley, and on publications of the Maryland Geological Survey. Only a small number of the many named stratigraphic divisions are shown, their selection and placement being the work of Wanless. A majority of the units are identified definitely with divisions recognized in adjacent parts of West Virginia, Ohio, and northwestern Pennsylvania, and generally the nomenclature of these beds is the same throughout the area indicated. Important key horizons include the Sharon coal, Lower Mercer and Upper Mercer limestones, Clarion coal, Vanport limestone, Lower Kittanning coal, Upper

Freeport coal, Brush Creek limestone, Ames limestone, and Pittsburgh coal. Not all named divisions of the southwestern Pennsylvanian column are recognized in Maryland, but most named units are the same in the two localities, or they are correlated definitely. The Lower Mount Savage coal of Maryland is the same as the Brookville coal of Pennsylvania, the Upper Mount Savage is the Clarion coal, the Ellerslie is the Lower Kittanning coal, and the Davis is the Upper Freeport coal.

Ashley calls attention to misidentification and lack of persistence of the Homewood sandstone in parts of southwestern Pennsylvania. Renick (1924) cited evidence showing that sandstone called Homewood along Beaver River is equivalent to the Clarion sandstone of the Allegheny River section, and thus he concludes that the so-called Homewood of the latter area actually corresponds to the Upper Connoquenessing sandstone.

Kanawha beds below the Brookville coal horizon contain many well-preserved plants, among which some of the most characteristic forms are *Neuropteris tenuifolia*, *N. gigantea*, *N. missouriensis*, *Alethopteris grandifolia*, *Eremopteris*, *Zeilleria*, and *Cannophyllites*. Among marine fossils from this zone are *Mesolobus striatus*, *Marginifera haydensis*, and *M. nana*.

The southwestern Pennsylvania region contains the type sections of Alleghenyan, Conemaughan, and Monongahelan beds. Almost universally the base of the Alleghenyan has been drawn at the base of the Brookville coal, but in the Pennsylvanian correlation chart the Alleghenyan is extended downward to include the Homewood sandstone. This sandstone, which lies just below the Brookville, is a clastic deposit, and such a unit, rather than a coal bed, logically belongs at the base of a series. Ashley disagrees with this definition of Alleghenyan, inasmuch as lowest workable coal of the Allegheny valley, originally designated as marking the base of the Alleghenyan, is the Lower Kittanning coal and not the Brookville. According to Ashley, therefore, the Alleghenyan should be defined as extending upward from the base of the Lower Kittanning coal, which corresponds to the Buck Mountain coal, just above the type Pottsville. All agree that the top of the Alleghenyan series belongs at the top of the Upper Freeport coal. Strata of southwestern Pennsylvania between the Brookville and Freeport coals have yielded a profusion of plant remains, including especially *Neuropteris ovata*, *N. rarinervis*, *N. scheuchzeri*, *Sphenophyllum emarginatum*, *Annularia stellata*, and pecopterids.

The Conemaughan series, which contains prominent red beds and lacks workable coals, extends upward to the base of the Pittsburgh coal. Characteristic plants from this division include *Pecopteris feminaeformis*, *P. polymorpha*, *Alethopteris grandini*, *A. magna*, *Odontopteris reichi*, *Lescuropteris moorii*, *Sphenophyllum oblongifolium*, and *Walchia*. Vertebrate remains from Conemaughan beds, including genera such as *Edaphosaurus* and *Eryops* which occur in uppermost Pennsylvanian and Lower Permian rocks of Texas, do not indicate equivalence in age of these deposits but similarity of climatic environment.

The top of the Monongahelan series has commonly been drawn at the top of the Waynesburg coal, and this boundary separating the "Upper Productive Measures" from the "Upper Barren Measures", or Dunkard group, is generally accepted as marking the top of the Pennsylvanian in the Appalachian region. Darrah (1937),

Schuchert (1943, p. 184), and others include the lower Dunkard (Washington) in the Monongahelan, inasmuch as *Callipteris* and other plants regarded as diagnostic of the Lower Permian first appear in the upper Dunkard (Greene). The Monongahelan floras closely resemble those of the Conemaughan, with dominance of pecopterids and common occurrence of *Odontopteris*. A plant not known from older rocks is *Taeniopteris*. Darrah correlates the Monongahelan with the upper Stephanian of Europe.

Northwestern Pennsylvania and southwestern New York (Column 9).—The Pennsylvanian section of this area corresponds closely to that of Ohio and southwestern Pennsylvania, but Monongahelan deposits are lacking. Ashley reports that recent studies by R. E. Sherrill show existence of a pre-Pennsylvanian erosion surface of considerable relief in northwestern Pennsylvania. Sherrill has traced the type Upper Mercer coal of Mercer County into the so-called Brookville coal of Clarion and Armstrong counties. The Mercer coal and limestone beds are classed as upper Pottsville (Kanawha), whereas the Brookville coal is commonly defined as lower Alleghenyan.

Ohio (Column 10).—Most of the stratigraphic units in the Pennsylvanian column of Ohio are named from localities in Pennsylvania. Correlations of the Ohio units with those in sections of western Pennsylvania, northern West Virginia, and eastern Kentucky are generally well established. The sequence of named divisions shown in Column 10 is based essentially on publications of W. E. Stout, but placement to show correlation is by Wanless who has traced many of the Ohio beds into adjoining States. Numerous measured sections and discussion of evidence for correlations have been published by Wanless (1939).

Fusulinids in upper Kanawha beds of Ohio, including *Fusulinella stouti* and *F. iowensis*, support correlation of these rocks with Pennsylvanian strata below the Rock Island coal horizon of Illinois, basal Cherokee shale of Iowa, and Atoka deposits in Oklahoma. Dunbar and Henbest (1942, p. 28) consider that *F. iowensis* defines a narrow subzone in which belong the Mercer limestone of Ohio, the Seville limestone of Illinois, and beds about 90 feet below the White Breast coal of Iowa.

The Putnam Hill limestone contains *Fusulina serotina* and *Fusulina leei*, and the Vanport limestone has yielded *Fusulina carmani*. These species are comparable to Desmoinesian forms common in Cherokee and Marmaton of the northern Midcontinent. Dunbar notes that correlation of the Putnam Hill with the Curlew limestone of Illinois and the Bluejacket horizon of northeastern Oklahoma is confirmed by fusulinids known from these beds.

The Brush Creek and Cambridge limestones bear fusulinids identified as *Triticites ohioensis*, which Dunbar interprets as indicative of early Missourian age. These horizons may be equivalent to the Livingston and Omega limestones of Illinois, which also contain this species, and they probably correspond to part of the Kansas City group in the northern Midcontinent.

The Ames limestone is reported to contain *Triticites skinneri* and typical *T. cullomensis*. Dunbar is confident that these Ames fusulinids are younger than the zone of *T. irregularis*, although this zone includes forms that are hardly distinguishable from *T. cullomensis*. The latter species is common in the Shawnee group, middle

Virgilian, and Dunbar thinks that the Ames may be as young as the Lecompton or Deer Creek limestones of Kansas. If this is true, a very considerable hiatus belongs in the Ohio section somewhere between the Ames and Cambridge horizons. The correlation chart shows the Ames in the position of upper Missourian. Alteration to indicate correlation of the Ames with the Lecompton or Deer Creek would require omission of a majority of named units in the Monongahelan division of eastern columns or a similar deletion of middle Pennsylvanian units elsewhere on the chart. The evidence for placement of the Ames limestone does not yet seem sufficiently definite to justify remaking the chart on the basis of assigning a materially higher stratigraphic position to it but the stratigraphic diagram on the chart indicates correlation of the Ames and Lecompton. Although some students of fusulinids have identified *T. cullomensis* from Missourian beds at Kansas City, Dunbar cannot corroborate occurrence of this species below the Virgilian in Kansas or Nebraska; he has recognized a form very close to *T. cullomensis* in upper Missourian strata of Texas, however.

West Virginia (*Columns 11, 12*).—Selection of named units shown in the West Virginia columns and correlation of these units are by Wanless who has been aided by field conferences with Read. Numerous measured sections and discussion of correlations have been published by Wanless (1939).

The Pennsylvanian column of northern West Virginia is closely similar to that of southwestern Pennsylvania and Maryland. Many stratigraphic units are definitely recognized as equivalents of Ohio beds, mainly in the upper part of the section. The Sharon coal horizon is distinguished by associated plants that characterize the Sewell coal horizon farther south. The prominent Roaring Creek sandstone, present both in northern and southern West Virginia, has been correlated with the Homewood sandstone by the West Virginia Geological Survey, but the position of this sandstone above the Kanawha black flint, which is correlated with the Zaleski flint of Ohio, leads Wanless to think that the Roaring Creek sandstone probably corresponds to the Clarion sandstone. These sandstones respectively occur a few feet below the No. 5 Block coal and its correlative, the Lower Kittanning coal. The Upper Freeport coal, marking the top of the Alleghenyan, is recognized in northern and southern West Virginia, Maryland, Pennsylvania, and Ohio. Several limestones and other units of Conemaughan and Monongahelan age are identified throughout this region and are known under the same names.

The southern West Virginia column is based on the work of D. B. Reger and reports of the West Virginia Geological Survey, supplemented by field studies of Wanless. This section shows marked expansion of the Kanawha, New River, and Pocahontas divisions of the Lower Pennsylvanian. A number of key horizons in this part of the section are tied to the Virginia and Tennessee columns and to sections in Kentucky. One of the most prominent and widespread sandstones is the Raleigh, which underlies the Sewell coal. It is traceable from Georgia to Tennessee where it is known as the Sewanee conglomerate and to Kentucky where it is designated Rockcastle conglomerate, and it is equivalent to the Sharon conglomerate of Ohio. The deposits below this horizon contain little conglomerate and bear a flora that is distinguishable from that of the Sewell coal horizon just below the Raleigh sandstone.

The Dingess and Winnifrede limestones, of Kanawha age, are key horizons identified rather confidently with the Kendrick and Magoffin beds, respectively, in Kentucky, and with the Lower and Upper Mercer limestones of Ohio and Pennsylvania. The Chilton coal, which occurs between the Dingess and Winnifrede limestones in southern West Virginia, contains a distinctive fireclay parting that is seen also in the corresponding Fireclay coal of Kentucky, locally called Dean, Hyden, or Bevins coal, and in the Windrock coal of Tennessee. The Kanawha black flint, of Alleghenyan age, is correlated with the Flint Ridge flint of Kentucky and the Zaleski flint of Ohio. The basis for this correlation is lithologic similarity, paleontologic character of associated beds, and like stratigraphic relations.

Alabama (*Columns 13 to 15*).—The columns representing the Coosa, Cahaba, and Warrior coal basins in Alabama are almost wholly derived from the report by Charles Butts on Paleozoic rocks of Alabama, description of the Bessemer-Vandiver quadrangle, and old reports of the Alabama Geological Survey. A short reconnaissance in the field was made by Wanless and Read.

The Mary Lee and Wadsworth coals are correlated with the Sewanee coal on the basis of David White's studies of fossil plants. Butts believes that the Alabama coal field sections include no strata younger than upper Pottsville. Wanless and Read report the discovery of definitely identified Pocahontas types of plants in the upper Parkwood, and poorly preserved plants resembling those from the Stanley shale of Arkansas were found in lower Parkwood beds. No satisfactory basis for precise correlation of the Alabama sections with others is now known.

Georgia (*Column 16*).—The Pennsylvanian of Georgia occupies two main areas, the Sand Mountain coal field and the Lookout Mountain coal field. They lie on opposite sides of the Lookout Valley in the northwestern corner of the state. Column 16, representing this district, was prepared by Wanless from reports by W. S. McCallie and from his own field observations. The Lookout Mountain field is characterized by the presence of two very prominent conglomeratic sandstones that are believed to represent the Warren Point sandstone and Sewanee conglomerate of Tennessee. The lower conglomerate of the Lookout Mountain field is less than 500 feet above the Mississippian in most sections. Coal beds occur a few hundred feet above the upper conglomerate. The section in the Sand Mountain field differs from that of the adjacent area just noted in having several hundred feet of coal-bearing strata below the conglomerates. Floras near the top of the Lookout Mountain section have a Sewell aspect. The pre-Sewell Pennsylvanian deposits of Sand and Raccoon mountains in northwestern Georgia seem to be about twice as thick as those of southern Tennessee, whereas in Lookout Mountain the pre-Sewell beds are a little thinner than in southern Tennessee.

Tennessee (*Columns 17, 18*).—The columns for Tennessee have been prepared by Wanless. They incorporate his field work, but column 17 is based essentially on studies by Glenn in the northern Tennessee coal field, and column 18 is derived largely from description by W. A. Nelson of the southern Tennessee coal field.

The Corbin conglomerate, prominent in southern Kentucky, extends into Tennessee, but because of its thin, weak character in this region the broad upland areas of northern Tennessee are capped by a hard sandstone that belongs stratigraphically

below the Corbin. This plateau-making sandstone is called the "Rockcastle" conglomerate even though it lies considerably higher in the section than the type Rockcastle conglomerate of Kentucky, which corresponds in position to the Sewanee conglomerate of Tennessee. Fossil plants collected by Read from the lower part of the Briceville formation are reported by him to be New River in age. The Lower Poplar Creek coal is overlain by a marine zone that closely resembles deposits just above the Williamsburg coal of Kentucky and the Quakertown coal of West Virginia. Correlations of the Blue Gem, Jellico, and some higher coals with coal beds in adjacent Kentucky and Virginia fields are now fairly well established. The Windrock coal, below the middle of the Scott formation, is correlated with the Fireclay or Dean coal of Kentucky and the Shelton of West Virginia on the basis of its position and content of a band of flint fire clay.

Striking overlap and thinning of the Pennsylvanian deposits are observed in tracing beds of the northern Tennessee coal basin toward the Nashville dome.

The southern Tennessee section of Pennsylvanian rocks is almost wholly confined to beds of Lee (Pocahontas and New River) age. Wanless believes that the oldest strata belong to the Quinnimont division of the New River, below the horizon of the Raleigh sandstone, although a few feet of basal strata may be of Pocahontas age. The well known flora that occurs with the Sewanee coal is almost identical to that of the Sewell coal horizon and accordingly the Sewanee (or Whitwell) coal is correlated with the Sewell.

Virginia (*Column 19*).—The Pennsylvanian rocks of Virginia range from lowermost Pottsville into the Alleghenyan. The column for this area was compiled by Wanless from his own field studies and reports of the Virginia Geological Survey, especially the Wise County report. This column is intended to apply also to Harlan and eastern Bell counties, Kentucky.

The strata from the base of the Pennsylvanian to the top of the Bee Rock conglomerate are assigned to the Lee formation. Nomenclature of the Pocahontas coals and immediately overlying units corresponds to that in southern West Virginia, but the Sewell coal is represented in this district by a bed known as the Lower Seaboard coal. Detailed information concerning the Lee formation between the Pocahontas field and central Tennessee area is scant, inasmuch as the Lee outcrop is restricted to a narrow belt of vertical beds in Stone and Cumberland mountains and Walden Ridge. Good exposures occur in a few gaps through these ridges. Accordingly, there is special difficulty in efforts to correlate the coals and associated strata on opposite sides of the Rocky Face cross fault, which extends from Cumberland Gap to Pineville Gap across the Middlesboro syncline. Wanless tentatively identified an unnamed limestone in the upper part of the Wise formation of Virginia as equivalent to the Magoffin limestone of Kentucky and Upper Mercer limestone of Ohio. David White has expressed the opinion that the Harlan sandstone, overlying the Wise formation, is of late Pottsville age, but Read thinks that it is possibly as high as middle Alleghenyan (Kittanning of Clarion sandstone).

Eastern Kentucky (*Columns 20 to 23*).—The eastern Kentucky columns of the chart have been prepared by Wanless. The Big Sandy River valley section (column 23) was constructed from several reports of the U. S. Geological Survey and Kentucky

Geological Survey, supplemented by Wanless' own field work. It shows the succession in the Kenova quadrangle, Pike County, the Russell Fork basin, and adjacent areas. In the southern part of the Kenova quadrangle there is a critical belt in which the relatively thin Ohio section of lower and middle Pennsylvanian beds expands very rapidly southward. Many new stratigraphic units are interpolated within a few miles. A similar belt is observed in West Virginia near Elkins and Webster Springs. Different names have commonly been applied to beds north and south of this belt, and additional detailed stratigraphic study is required to establish correlations definitely. The Big Sandy River section extends from basal Kanawha strata to a horizon slightly above the Ames limestone. The Kendrick shale and Magoffin limestone marine horizons are traced into adjoining areas. The Winslow (No. 6) coal is identified as equivalent to the Lower Kittanning coal.

The Kentucky River section (column 22) is described in several reports of the Kentucky Geological Survey. The principal coal beds are known by different names along the north, middle, and south forks of the Kentucky. Field studies by Wanless have been confined to the section above the Manchester coal but he thinks that satisfactory correlations in this basin and between this basin and adjoining areas have been determined.

The Lower Cumberland River section (column 21) is given essentially from field work by Wanless, but reports by W. R. Jillson on coals of the Stinking Creek area were also used. Along the divide between the Kentucky and Cumberland drainages the section extends at least 700 feet above the Magoffin limestone, but these higher beds are mostly lacking or imperfectly known in the Lower Cumberland valley. Correlation of the Jellico, Blue Gem, and associated coals of this section with the important coal beds of mid-Kanawha position in West Virginia, Virginia, and other areas is not satisfactorily established. Several unnamed prominent conglomeratic sandstones between the Rockcastle and Corbin conglomerates of this area can be traced into known units of the West Virginia and Tennessee sections.

The Cumberland Gap coal field section (column 20) is taken from the report by Ashley and Glenn on this district and principally represents the area west of the Rocky Face fault. The formation names have not been used outside this district. Seemingly there is a marked increase in the number of thin coal beds, especially in the interval between the Poplar Lick and Red Spring coals, and this tendency is even more marked in the so-called Scott formation of northern Tennessee. The only beds of Lee age that have been named in this area are the Naese sandstone and Cumberland Gap coal, although a striking succession of sandstones and conglomerates is exposed in Pine and Cumberland mountains. The Cumberland Gap column was prepared by Wanless.

EASTERN INTERIOR REGION

Michigan (*Column 24*).—Knowledge of Pennsylvanian deposits in Michigan is very adequate. These strata, mostly concealed by glacial cover, are isolated from other coal-bearing basins, and correlation is hence dependent mainly on paleontologic evidence. The column for this State is based on publications of the Michigan Geological Survey and papers by W. A. Kelly. Except for the Woodville sandstone,

correlation of which is conjectural, the Michigan Pennsylvanian rocks are all older than Missourian. The Saginaw formation contains *Fusulinella?*, *Mesolobus*, *Marginifera missouriensis*, *Spirifer occidentalis*, and *Dictyoclostus morrowensis* (Kelly, 1930; 1933), which denote Desmoinesian or Lampasan age. *Mesolobus* seems to be restricted to post-Lampasan deposits in the northern Midcontinent, but in southern Oklahoma and east of the Mississippi it occurs in zones classed as upper Lampasan. Whether the form identified as *Fusulinella?* really belongs to this genus or to another having higher range is not known. Kelly (1933) has differentiated eight cyclical formations (cyclothems) in the Pennsylvanian section near Grand Ledge, Michigan.

Indiana (*Column 25*).—The Pennsylvanian section of Indiana corresponds closely to the sequence of beds of equivalent age in eastern and southern Illinois and western Kentucky. The classification and nomenclature of stratigraphic units as shown in column 25 is based on reports of the Indiana Geological Survey and description of the Ditney quadrangle by the U. S. Geological Survey. Correlation of the Indiana section with adjoining areas is by Wanless and Weller (1939). The Hindostan beds at the base of the Indiana Pennsylvanian contain a well-preserved flora that Read correlates with a horizon of the Pocahontas group (lower Lee) in Virginia (Wanless, 1939). The Minshall coal and overlying Minshall limestone are identified as equivalent respectively to the Rock Island No. 1 coal and Seville limestone of Illinois. Wanless and Weller believe that the Seville is also equivalent to the Curlew limestone of western Kentucky and southern Illinois, but Dunbar and Henbest (1942), on evidence from fusulinids, are confident that the Curlew is younger than the Seville. Detailed discussion of the correlation of Pennsylvanian rocks of Indiana has been published by Wanless (1939).

Wanless (September 1943) reports that detailed studies by Donald W. Franklin in southern Indiana reveal the presence of 10 marine limestones below the probable position of the Seahorne limestone. These beds are distributed through a stratigraphic range of 275 feet that reaches below the Lower Block coal. Possibly the Seville and Curlew are equivalent to two different limestones. Fossils from some of Franklin's localities, studied by Chalmer Cooper, are reported to be closely similar to upper Wapanucka and Bostwick forms from Oklahoma.

Western Kentucky (*Column 26*).—Stratigraphic units named in this column are based on several reports of the Kentucky Geological Survey. Their correlation is the work of Wanless and Weller, who have spent considerable time in field studies directed to the comparison of the western Kentucky deposits of Pennsylvanian age with those in Illinois. Graphic sections and evidence for correlations have been published recently by Wanless (1939).

Illinois (*Columns 27 to 30*).—Stratigraphic studies, mainly by Weller and Wanless, in recent years have profoundly modified conceptions of Pennsylvanian deposits of the Illinois basin. This work has established numerous precise correlations both between units exposed on different sides of the basin and between Illinois divisions and those of near-by areas. The columns for this district are by Weller and Wanless. Reference may be made to the several papers of these geologists for detailed descriptions and discussion of evidence for correlations.

The Caseyville formation contains fossil plants just above the Battery Rock coal that have been identified by White and Read as typical of the Sewell coal horizon (middle Lee) in Virginia, Sharon coal horizon in Ohio, and Morrowan in Arkansas. According to Wanless, marine fossils of the Sellers limestone are closely similar to forms found in the Sharon ore bed of Ohio and in Morrowan rocks of the Midcontinent.

The Tradewater formation, as defined in southern Illinois, is nearly equivalent to the Kanawha, as restricted in the chart, or the Lampasan. This represents the zone of *Fusulinella*. Dunbar and Henbest (1942) recognize *Fusulinella* in the Boskydell horizon of the lower Tradewater and define this as the oldest known marine zone of post-Morrowan age in Illinois. The Seville limestone contains *Fusulinella iowensis*, *F. iowensis stouti*, and *F. gephyrea;* it is correlated with the Mercer limestone (upper Kanawha) of Ohio and with a zone 90 feet below the White Breast coal of Iowa. Weller and Wanless agree that the Seville is almost certainly equivalent to the Minshall limestone of Indiana, but correlation with the Curlew, which they have suggested, is less definite. Dunbar and Henbest think that the Curlew limestone, which contains *Fusulina leei* but no known *Fusulinella*, is younger than the Seville. Weller emphasizes the faunal distinction that separates Seville and lower strata, which contain *Mesolobus striatus* and *Marginifera haydenensis*, from beds at and above the horizon of the Stonefort limestone in Illinois and the Munterville limestone in Iowa, which lack the species just named but contain *Mesolobus mesolobus* and *Marginifera muricatina*. The faunal change here noted is recognized at a corresponding horizon eastward at least as far as Ohio and westward into Oklahoma.

Beds of Desmoinesian age in Illinois, representing the zone of *Fusulina*, extend from somewhat below the horizon of the Curlew limestone to a little above the Lonsdale limestone. Dunbar and Henbest (1942) have described numerous species of *Fusulina* from the Curlew, Stonefort, Seahorne, Oak Grove, St. David, Absher, Brereton, Herrin, Bankston Fork, Piasa, Cutler, and Lonsdale limestones. *Wedekindellina* occurs also in the Stonefort, Seahorne, and Oak Grove. *F. leei*, which is found in the Curlew limestone, also occurs in the Putnam Hill limestone of Ohio. The Oak Grove limestone is a distinctive marker bed that is definitely recognized in western, southern, and northern Illinois. It is considered equivalent to the Velpen limestone of Indiana and the Ardmore limestone of Iowa, Missouri, and Kansas. Fusulinids of the Piasa and Lonsdale limestones are identical with species found in the upper Pawnee, Altamont, and Lenapah limestones of the northern Midcontinent area.

The upper limit of *Mesolobus*, *Fusulina*, and other fossils typical of the Desmoinesian series is the base of the Trivoli cyclothem in Illinois, which is slightly below the No. 8 coal in the McLeansboro formation. Upward from this horizon to an indefinitely determined position above the LaSalle or Livingston limestone, the strata are Missourian in age. They belong to the zone of *Triticites irregularis*. Dunbar states that *T. ohioensis* and *T. venustus*, which occur in the Livingston and Omega limestones of Illinois, belong to the tribe of *T. irregularis*, and he judges them to be more primitive than forms found in the upper Missourian (Lansing) of the northern Midcontinent region. Accordingly, he thinks that the Livingston and Omega are equiva-

lent to part of the Kansas City group, probably the lower part. (See diagram on chart.) The same fusulinid fauna occurs in the Brush Creek and Cambridge limestones of Ohio, which are correlated in the chart with beds in the lower part of the Kansas City group. Possibly these Ohio limestones correspond to Illinois and Midcontinent beds slightly higher than those indicated as correlatives on the chart but this is uncertain.

The uppermost part of the Pennsylvanian section in parts of Illinois is considered to be Virgilian in age. The Shumway limestone contains *Triticites turgidus* and *T. pauper*, which are not definitive for correlation. Weller thinks that the Omega limestone may be as young as middle Shawnee (Deer Creek), and he tentatively correlates the Shumway with upper Shawnee (Topeka). This is very doubtful. A limestone called Greenup, which crops out in central Illinois, is thought by Weller to equal the Omega. Dunbar and Henbest find no Omega fusulinids in the Greenup but report a robust species of *Triticites* closely similar to *T. ventricosus* from the upper Virgilian. Dunbar (personal communication) thinks that the Greenup is much younger than the Omega limestone and suggests that it may represent an overlap of late Virgilian deposits, like the so-called Fort Dodge beds near Fort Dodge, Iowa—an isolated outcrop of strata bearing Shawnee types of fusulinids that rests on Desmoinesian. Most recent work by Wanless, utilizing electric well logs and other subsurface data, indicates that the Greenup limestone is about 500 feet above the Livingston, whereas the Omega is about 250 feet above this datum. Weller concurs in viewing the evidence of pre-Greenup age of the Omega as convincing.

MIDCONTINENT REGION

Iowa (*Column 31*).—The Pennsylvanian column of Iowa, as shown in the correlation chart, is the work of Cline, who has been most active in recent years in field studies of the Desmoinesian rocks of the type region. Condra has been responsible largely for development of present knowledge of Missourian and Virgilian strata of southwestern Iowa. Correlations with Pennsylvanian horizons of adjacent States have been determined by Iowa geologists, aided by Weller and Wanless in identifying Illinois equivalents, and by Condra, Greene, Jewett, and Moore in establishing firm correlations with units in Missouri, Nebraska, and Kansas. Almost all horizons of the Iowa section are very precisely correlated with named Pennsylvanian units of near-by States.

The basal part of the Iowa Pennsylvanian belongs to the zone of *Fusulinella*, inasmuch as Thompson (1934, p. 296) has described *F. iowensis* from a bed about 90 feet below the White Breast coal. Rocks called lower Cherokee on the chart are here assigned to the Lampasan series, although they have not been differentiated previously from the Desmoinesian. The *F. iowensis* zone in Iowa is correlated with the Seville limestone of western Illinois.

Correlation of all named Desmoinesian units of Iowa with beds in Illinois, as indicated on the chart, is agreed to by Cline, Weller, and Wanless. The St. David limestone of Illinois is deemed equivalent to the Houx limestone (Middle Fort Scott) of Iowa and Missouri, rather than the Higginsville limestone, which is the Upper Fort Scott limestone of Kansas. The Houx is a very thin bed occurring between

the Lower and Upper Fort Scott in western Missouri, but northward it becomes increasingly prominent. The Brereton limestone of Illinois is correlated with the Myrick Station member of the Pawnee limestone of Iowa, Missouri, and Kansas. The Exline limestone, named by Cline from a locality in Iowa, is recognized as equivalent to the "black limestone" of the Peoria, Illinois, region, and accordingly Exline has been introduced into the western Illinois Pennsylvanian section. The Exline is correlated with the "*Trepospira* band" in northwestern Missouri. Cline is convinced of the Desmoinesian age of the Exline, but Greene believes that the *Trepospira* zone should be classified as lower Missourian. Correlation of Iowa and Missouri beds of Desmoinesian age has been determined by field tracing and careful comparison of sections.

According to Dunbar (personal communication) fusulinid evidence is irreconcilable with correlations of the Brereton, and part of the Pawnee limestone. The Brereton, Herrin, and Bankston Fork limestones of Illinois carry the distinctive *Fusulina girtyi* assemblage, whereas the Piasa and Cutler of Illinois contain the very different large, elongate fusulinids of the *F. eximia-F. megista* fauna, which is characteristic of the Pawnee limestone.

Confusion in identification of equivalent strata in the Missourian and Virgilian parts of the sections of Iowa, Nebraska, Missouri, and Kansas that existed a decade or more ago has been removed. All the units shown on the chart and many unnamed ones are now recognized definitely throughout the northern Midcontinent area. Even small subdivisions of many formations and members are identified very widely, and by applying stratigraphic criteria learned from study of cyclic sedimentation these identifications can be affirmed with unusual positiveness. The highest known Pennsylvanian deposits of Iowa belong between the Dover and Brownville limestones, near the top of the Wabaunsee group, uppermost Virgilian. Dunbar (personal communication) reports that the outlier of supposed Permian limestone near Fort Dodge, known as the Fort Dodge beds, contains numerous fusulinids of Shawnee type. These rocks, probably mid-Virgilian, rest disconformably on Desmoinesian.

Missouri (*Column 32*).—Studies by Hinds and Greene are the chief basis for classification of the Pennsylvanian deposits of Missouri. Greene has been active for many years as geologist working on these rocks for the Missouri Geological Survey, and he is responsible for column 32 of the chart. All named units and many others are recognized definitely in adjoining States, but the Missouri classification and nomenclature of several divisions differ from those applied to the Pennsylvanian in near-by sections. This does not mean uncertainty in identification or lack of continuity of beds.

Kansas and Nebraska (*Column 33*).—This column reflects the work of numerous geologists during recent years, as well as earlier investigators. Present detailed knowledge of outcropping Pennsylvanian stratigraphic units in this area is mainly credited to Condra, Dunbar, Jewett, Moore, R. G. Moss, Newell, and E. C. Reed. Cyclic sedimentation is recognized as a prevailing attribute of the northern Midcontinent Pennsylvanian deposits, and application of criteria based on studies of Kansas cyclothems and megacyclothems (Moore, 1937) has contributed greatly to elucidation of problems in stratigraphic classification and correlation.

Whether or not basal Cherokee deposits of this region include strata as old as Lampasan is very uncertain, but, if so, pre-Desmoinesian beds are thin and local.

Fusulinids from the Bluejacket horizon in the Cherokee shale are reported by Dunbar to indicate approximate equivalence in age to the Stonefort limestone of Illinois and Putnam Hill limestone of Ohio. Limestone and shale divisions of the Marmaton group are traced from Kansas into Missouri and northeastern Oklahoma, precise identifications of almost every unit being made. *Mesolobus mesolobus*, *Marginifera muricatina*, *Fusulina girtyi*, *F. haworthi*, *Wedekindellina euthysepta*, *Prismopora*, and other characteristic Desmoinesian marine fossils are abundant in various zones, but none of these forms ranges above the Lenapah limestone.

The Missourian and Virgilian series are defined by significant but obscure disconformities and by faunal distinctions. Stratigraphic subdivisions of both series have been traced into adjoining areas, and correlations of this part of the section, as shown on the chart, are firm. Limestones of the lower and upper Missourian and some limestones of Virgilian age thin southward and disappear, but various key horizons can be followed long distances. Changes in classification and nomenclature of units reflect lateral variation in the nature of the deposits, although in part they represent locally established usage that is not based on difference in stratigraphic relations.

Northwestern Arkansas, northern Oklahoma, southern Kansas (Column 34).—The classification and placement of stratigraphic units shown in column 34 is based mainly on work by Dott, Miser, Moore, Newell, and M. E. Oaks. Condra has contributed to studies on correlation of Virgilian beds.

Morrowan deposits, which have their type locality in northwestern Arkansas, are considered by Miser and others to correspond to at least parts of the Jackfork sandstone and Johns Valley shale of the Ouachita Mountains region and to upper Springer and lower Wapanucka limestone of the area north of the Arbuckle Mountains. The Baldwin coal horizon in the Bloyd shale yields a rich, well-preserved flora that has been studied by David White who makes unqualified correlation of the horizon with the Sewell coal and equivalents of the Appalachian region. This is mid-Lee or early Pottsville in age.

Conglomerate, sandstone, and shale that rest unconformably on Morrowan deposits in northwestern Arkansas formerly were called the Winslow formation but now are classed as Atoka. Fossils of the Atoka formation, especially *Fusulinella prolifica*, *F. fittsi*, and *F. oliviformis*, indicate Lampasan or Kanawhan age. North of the Arkansas River in northeastern Oklahoma, Pennsylvanian beds occurring between Morrowan and the Fort Scott limestone are called Cherokee shale. The basal Cherokee of this region is classed as Lampasan, inasmuch as the Little Cabin sandstone has been traced by Newell and C. W. Wilson, Jr., so as to identify its essential stratigraphic equivalence to the Warner sandstone member in the middle part of the McAlester formation near Muskogee, Oklahoma. A persistent sandstone below the Little Cabin is considered to represent the Blackjack sandstone member of the Atoka formation. Presumably, the Lampasan portion of the Cherokee in this region is separated by a hiatus from Desmoinesian deposits, but this is not established by field evidence.

In the Desmoinesian portion of the northeastern Oklahoma section, several named units have been traced definitely northward into Kansas and southward into the Arkansas Valley region of east-central Oklahoma. The Bluejacket sandstone is identified near the base of the Boggy formation, and the Tiawah limestone is found

to belong in the upper Boggy. Dunbar reports that fusulinids from the Spaniard Creek limestone member of the Savanna formation are the same as forms in the Stonefort limestone of Illinois, and others from the Bluejacket horizon are closely similar to fusulinids found in the Curlew and Putnam Hill limestones. The Verdigris limestone has been traced northward into the Ardmore limestone, and a sandstone called "Squirrel" just below the Mulky coal is followed southward into the Calvin sandstone. The Fort Scott limestone disappears in the latitude of Tulsa, but mapping by A. N. Murray has established the position of this horizon in the middle portion of the Wetumka shale. According to work by Newell and Dott, a prominent sandstone that appears in the Labette shale north of the Arkansas River is the same as the basal sandstone of the Wewoka formation, and this sandstone can be traced southward nearly to the Arbuckle Mountains. Limestones of the Marmaton group in northeastern Oklahoma are readily followed into Kansas, but it is now known that the formation called Oologah limestone is chiefly, if not exclusively, an expanded development of the Pawnee limestone. Diagnostic Desmoinesian fossils are abundant at numerous horizons extending upward to the top of the Lenapah limestone but not higher.

Deposits of Missourian age in this region are characterized by an increase in the proportion of clastic sediments as compared with corresponding strata farther north. Key horizons that can be followed long distances are: (1) the Checkerboard limestone, which is stratigraphically below the Hertha limestone of Kansas; (2) the Hogshooter limestone, which represents a continuation of the Dennis limestone of Kansas; (3) the Dewey limestone, identified definitely as equivalent to the Drum limestone; and (4) the Avant limestone, which corresponds to part of the Iola limestone. Limestone and marine shale in the upper part of the Missourian section occupy the position of Lansing beds and carry distinctive fossils of this zone. A large number of crinoids occur in the Missourian rocks of this area.

Lower Virgilian strata are distinguished by prominence of continental sandstone and red shale belonging to the Nelagoney formation. Detailed stratigraphic studies have established the identity of the Oread, Lecompton, Deer Creek, and Brownville limestones by tracing them southward in the field. Similarly, the Turkey Run limestone is found to represent part of the Topeka limestone of Kansas; the Bird Creek is the southward continuation of middle Howard limestone; the "*Cryptozoon* limestone" is a bed in the Wakarusa limestone; and the Stonebreaker limestone corresponds to the Reading and Elmont. Numerous fossil zones and lithologically distinctive units have been traced from Kansas many miles southward into Oklahoma. Channel sandstone considered to belong at the base of the Permian system rests disconformably on upper Wabaunsee beds in this region.

Ouachita Mountains and Arkansas Valley, Oklahoma, Arkansas (Columns 35, 36).—Classification and correlation of the Pennsylvanian rocks of the Ouachita Mountains region and adjacent territory in the Arkansas River Valley have been indicated on the chart mainly according to work by Miser and Hendricks.

Sandstone and shale several thousand feet thick in the Ouachitas, called Hot Springs, Stanley, Jackfork, and Johns Valley, are considered to be early to middle Pottsville in age. White (1937) has reported that plant remains from the Stanley and

Jackfork are Pennsylvanian types that most closely resemble species from the Pocahontas and lower Lykens groups of the Appalachian region; they are distinctly older than the flora of the Bloyd shale in northwestern Arkansas and equivalent Sewell and Sewanee plants. Strata considered equivalent to the Stanley-Jackfork and Johns Valley are named Springer and Wapanucka in a belt along the northwest margin of the Ouachitas and adjoining the Arbuckle Mountains. The Wapanucka limestone and associated marine shale contain numerous distinctive fossils that characterize Morrowan beds of northwestern Arkansas.

A hiatus of considerable importance separates Morrowan deposits of the Ouachita and Arkansas Valley region from overlying conglomerate, sandstone, and shale called Atoka formation. This is indicated both by physical evidence and by contrast in paleontologic characters of beds. Atoka beds of southern Oklahoma have yielded *Fusulinella fittsi*, *F. oliviformis*, and other fusulinids that indicate correlation with early Pennsylvanian deposits in Iowa and strata near the horizon of the Seville limestone of Illinois and the Mercer limestone of Ohio. Read (Hendricks and Read, 1934) has studied numerous collections of plants from the Hartshorne and McAlester formations, which overlie the Atoka, and he considers the floras from these horizons to be earliest Alleghenyan in age. On the other hand, they may be correlated about as well with slightly older plants of Kanawhan age, which occur below the Brookville coal horizon. According to Read (Hendricks and Read, 1934), the Hartshorne flora contains *Linopteris gilkersonensis*, *Neuropteris rarinervis*, *N. capitata*, *Sphenophyllum suspectum*, and *S. lescurianum*, and the McAlester flora has *Mariopteris sphenopteroidea* and *Pecopteris richardsoni*. These correspond to upper Pottsville forms of the Appalachian region, but there are few of these forms that do not range into lower Alleghenyan beds.

Correlation of rocks of Desmoinesian age, as shown on the chart, is based on field mapping, identification of key subsurface horizons, and paleontologic characters. Relations to the northeastern Oklahoma section are indicated partially in the discussion of column 34. Read (Hendricks and Read, 1934) emphasizes the significance of *Neuropteris desorii*, which first appears in lower Savanna beds. This form is not known below the Kittanning coal group of the Alleghenyan series in the Appalachian area, and according to Read the Savanna, which contains abundant *Linopteris rubella* and *Neuropteris scheuchzeri*, is probably not older than Kittanning or Clarion. Fossil plants of the Boggy shale, which include abundant *Mariopteris occidentalis* and *Neuropteris ovata*, are considered middle to late Alleghenyan. The lowest reported occurrence of *Mesolobus* in this section north of the Coalgate coal basin is a form from the Savanna formation, identified by Wilson as *M. striatus*. A disconformity occurs at the base of the Savanna, but in territory northeast of the Arbuckle Mountains all this formation and deposits of early Boggy age are lacking throughout a large area. Lampasan strata are also absent in parts of this region, so that upper Boggy beds rest directly on Wapanucka limestone. Another break that may represent an important interruption in sedimentation is reported at the base of the Thurman sandstone. Newell has observed that only about 40 per cent of the marine fauna of the Boggy formation is recognized in the Wetumka and higher beds. The highest occurrence of *Mesolobus* and other distinctive Desmoinesian fossils is in the Holdenville formation.

The Seminole formation in south-central Oklahoma contains prominent coarse grits that have been traced northward into sandy deposits marking the base of the Missourian series. Mapping also indicates that the DeNay limestone, at the base of the Francis formation, is essentially, if not precisely, equivalent to the Checkerboard limestone. The Belle City limestone is correlated with the Dewey limestone of northeastern Oklahoma on the basis of similarity in stratigraphic position, lithology, and fossil content. One has not been traced into the other along the outcrop, but continuity may be established by subsurface studies. Upper Missourian deposits seem to be lacking in south-central Oklahoma.

The Vamoosa, Ada, and Vanoss formations consist mainly of red sandstone, red shale, and conglomerate. Darcie Green has traced part of the Pawhuska limestone, identified as equivalent to the Deer Creek limestone, from northern Oklahoma nearly to the Arbuckle Mountains, and this horizon is reported by him to belong in the Ada formation.

Ardmore basin, southern Oklahoma (*Column 37*).—The Pennsylvanian rocks of the Ardmore basin, south of the Arbuckle Mountains in southern Oklahoma, have been studied by Tomlinson, who contributed material for column 37 of the correlation chart.

The Springer group contains microfossils that B. H. Harlton (1934) reports correspond to forms found in the Stanley shale and Jackfork sandstone of the Ouachita Mountains region. The Jolliff and Otterville limestone, together with associated shaly strata, yield numerous marine fossils that are unquestionably the same as characteristic Wapanucka and Morrow species. These beds overlying the Springer, which Tomlinson classes as belonging to the lower part of the Dornick Hills group, contain distinctive microfossils, according to Harlton, that furnish basis for correlation with the Johns Valley shale and Wapanucka.

The Bostwick limestone, which is locally conglomeratic, the Lester limestone, and other parts of the upper Dornick Hills group contain *Fusulinella* closely similar or identical to *F. fittsi* from lower Atoka beds northeast of the Arbuckles. These beds are identified as belonging to the Lampasan series. Marine fossils are very abundant at some horizons. Westheimer reports that undescribed fusulinids from the Frensley limestone are the same as forms found in the so-called Red Oak member near the top of the Atoka formation in T. 1 N., R. 8 E., Oklahoma. *Mesolobus* makes appearance just above the Lester limestone and at some horizons in the upper Dornick Hills shells belonging to this genus are extremely abundant. *Mesolobus* is also reported by Westheimer from beds called upper Atoka in the Mill Creek syncline and from well samples just above the lower Atoka "lime group", the upper part of which is tentatively correlated with the Lester limestone, in the Fitts oil field southwest of Ada, Oklahoma. These occurrences of *Mesolobus*, which are interpreted to belong considerably below the horizon of lowest known specimens of the genus (in the Savanna formation) north of the Coalgate basin, may be compared to distribution of *Mesolobus* in the Seville and Mercer limestones of eastern areas.

Predominantly sandy lower Deese deposits of the Ardmore basin are correlated with the Savanna formation, in which sandstone also is prominent. Fusulinids from the Devil's Kitchen horizon in the Deese are considered by M. P. White to belong

stratigraphically below the base of the Boggy formation. The Arnold limestone is correlated with upper Boggy beds by Westheimer and tentatively with middle Millsap Lake beds, at about the horizon of the Brannon Bridge limestone, by Tomlinson. The Rocky Point conglomerate, about 1500 feet above the Arnold limestone, is considered by Tomlinson and White to be approximately equivalent to the basal sandstone of the Wewoka formation farther north in Oklahoma and to the Brazos River conglomerate member of the Garner formation in north-central Texas. A distinctive undescribed species of *Fusulina* found in the Wewoka formation occurs also in the upper third of the Deese, according to Westheimer, who also reports the occurrence of an identical species of *Fusulina* associated with highest *Mesolobus* in the Confederate limestone and Holdenville formation.

Lower Hoxbar beds are Missourian in age. The base of the Hoxbar group is here drawn above the Confederate limestone, rather than just below it, inasmuch as the boundary between Desmoinesian and Missourian deposits preferably should coincide with the Deese-Hoxbar contact. The Anadarche limestone contains numerous fusulinids of the *Triticites irregularis* group, which occur also in the Belle City limestone north of the Arbuckles and in the Palo Pinto and Graford of north-central Texas.

Upper Hoxbar deposits, including the Zuckerman sandstone, are tentatively correlated by Tomlinson and others with the Vamoosa and Ada formations and may be Virgilian in age.

North-central Texas (Column 38).—The classification and correlation of the north-central Texas Pennsylvanian, as shown in column 38 of the chart, are mainly the work of Cheney.

No representative of thick Springer or Stanley-Jackfork clastic deposits of very early Pennsylvanian age is known at the outcrop in north-central Texas, but such beds seem to be present beneath overlapping Cretaceous rocks in the geosynclinal belt that trends southward on the east side of the Llano uplift. Despite inconspicuousness of the disconformity at the base of the Marble Falls limestone, a great hiatus seems to occur between oldest known Pennsylvanian strata exposed around the Llano uplift and underlying Mississippian rocks. Studies by Plummer indicate that the so-called Marble Falls limestone really consists of two distinct formations, the lower of which is Morrowan in age and the upper post-Morrowan. The name Marble Falls is restricted to the lower formation, as shown on the correlation chart. Distinctive marine fossils, especially including corals, brachiopods, and crinoids, furnish basis for correlation with the Wapanucka limestone and type Morrowan deposits.

A disconformity separates Morrowan limestone from overlying strata in north-central Texas. Cheney has applied the name Lampasas series to beds that include the Big Saline group ("Upper Marble Falls limestone") and Smithwick group. These beds contain *Fusulinella llanoensis, Fusiella primaeva,* and other fossils that indicate age equivalence to the middle and upper Dornick Hills beds of the Ardmore basin and Atoka deposits. Among cephalopods, a group of species defined by Plummer and Scott as the *Gastrioceras listeri* assemblage is recognized in Big Saline and Smithwick rocks of the Llano area, in lower Atoka deposits of Oklahoma, the Kendrick shale of eastern Kentucky, lower Magdalena limestone of the Sierra Diablo in western

Texas, and in zone G of the northwestern European Carboniferous section. A characteristic ammonoid of this zone in north-central Texas is *Paralegoceras texanum*.

The Strawn series, of Desmoinesian age, rests unconformably on Lampasan deposits which were locally deformed and eroded considerably before the beginning of Strawn deposition. The Millsap Lake group contains numerous specimens of *Fusulina eurytei.·es*, *F. haworthi*, *F. novamexicana*, *Wedekindellina euthysepta*, *Mesolobus*, *Chaetetes*, and other fossils that define Desmoinesian age. The East Mountain shale at the top of the Strawn also contains *Mesolobus* and numerous distinctive crinoids, bryozoans, and other marine invertebrates belonging to this assemblage. The *Gastrioceras venatum* assemblage of ammonoids, reported by Plummer and Scott from upper Millsap Lake beds, occurs also in the Wewoka formation of Oklahoma and lower Gaptank deposits of western Texas.

The Canyon series is redefined by Cheney to correspond exactly to the span of the Missourian series, and thus it includes beds formerly classed as upper Mineral Wells and other deposits below the Palo Pinto limestone. Variation in usage of stratigraphic names by many writers on the north-central Texas Pennsylvanian rocks necessitates reference to the literature in order to define application of most terms. Marine fossils are abundant at many horizons, and these furnish excellent basis for recognition of Missourian age. *Triticites* of the *T. irregularis* tribe is widespread and easily distinguished. Numerous species of crinoids are common to the lower and middle Canyon of Texas and the Kansas City-Lansing deposits of the northern Midcontinent. *Paraschistoceras reticulatum*, *Prouddenites bösei*, *Goniolobeceras gracellense*, *Glaphyrites kansasensis*, *Parashumardites fornicatus*, and other ammonoids described by Plummer and Scott from the Graford formation occur also in the Nellie Bly formation of Oklahoma (Miller and Cline, 1934) and in the Drum limestone of Kansas (A. N. Sayre, 1931).

The Cisco series, as defined by Cheney (1940), excludes the upper part of the Cisco group recognized by the Texas Bureau of Economic Geology, which, in turn, excludes still higher beds that originally were classed as belonging to the Cisco. Diversity of usage by many geologists in definition of this term, like that of Canyon and other Texas Pennsylvanian names, is an unfortunate source of confusion that might be avoided by adoption of time-rock terms such as Missourian and Virgilian. Precise correlation of units in this part of the section with Douglas, Shawnee, and Wabaunsee horizons is not now possible. Fusulinids belonging to the zone of *Triticites cullomensis* are abundant in the Graham formation. *T. beedei*, common in the Wayland shale, occurs also in the Deer Creek limestone of Kansas. *T. secalicus*, identified by Henbest (1938) from a number of Graham zones, is reported in the northern Midcontinent to range from the Plattsburg limestone to the Howard limestone. *T. plummeri*, a distinctive Wayland fusulinid that Henbest recognizes also in the Breckenridge limestone, occurs in the Oread and Deer Creek limestones of Kansas. The robust *T. ventricosus*, which characterizes Wabaunsee and lowermost Permian beds of Kansas, occurs commonly also in the Thrifty and Harpersville formations of Texas. The *Uddenites schucherti* fauna, which includes *Marathonites sulcatus*, *M. ganti*, *Agathiceras frechi*, *Schistoceras diversecostatum*, *Paraschistoceras hildrethi*, *Vidrioceras irregulare*, and other forms, occurs in the Wayland shale of north-central Texas and

upper Gaptank beds of western Texas. The Pennsylvanian-Permian boundary in north-central Texas is drawn at a widespread disconformity that occurs between the horizons of the Waldrip-Newcastle coal, below, and the Saddle Creek limestone, above. Numerous marine fossils corresponding to species in the Admire, Council Grove, and Chase groups of the Kansas Lower Permian make appearance in the Saddle Creek and overlying strata of Texas.

ROCKY MOUNTAINS AND COLORADO PLATEAU

Western Texas (Columns 39 and 40).—The sequence of Pennsylvanian rock divisions in the Marathon region of western Texas, as given in the chart (column 39), is based mainly on the work of P. B. and R. E. King. Detailed discussion of the correlation of fossil-bearing zones has been published by P. B. King (1940) .

The El Paso region (column 40) contains Pennsylvanian deposits that have been described recently by L. A. Nelson (1940). Seemingly, the oldest strata in this area are post-Morrowan, and the youngest are pre-Missourian. *Mesolobus* and *Fusulina* are reported from the Berino and Bishop's Cap members of the Magdalena formation but not from the underlying La Tuna member.

New Mexico (Column 41).—Pennsylvanian deposits in New Mexico have generally been assigned to the Magdalena formation (as shown at the right of column 41). Recently, Thompson (1942) has subdivided the Magdalena into four series, each containing two groups. These divisions are best represented in southern New Mexico, but middle and upper ones are recognized throughout the central and northern parts of the State. The columns of the correlation chart representing New Mexico indicate Thompson's work.

Oldest Pennsylvanian strata, considered to be post-Morrowan and pre-Desmoinesian, are called the Derry series. They contain numerous fusulinids at various horizons; Thompson reports *Millerella*, *Ozawainella?*, *Schubertella* ("*Eoschubertella*"), *Staffella* ("*Pseudostaffella*"), and *Fusulinella*. Fusulinids from the basal Derry are stated to be identical with forms occurring about 150 feet below the top of the type Marble Falls limestone (?Big Saline).

Desmoinesian rocks are characterized by the occurrence of *Mesolobus*, *Chaetetes*, and the fusulinids *Fusulina*, *Wedekindellina*, *Schubertella*, *Staffella*, and *Millerella*. The Sandia formation is interpreted by Thompson as a local deposit in the Sandia Mountains.

Missourian deposits extend from southern New Mexico in the Mud Springs, Ladron, and Hueco Mountains into the Nacimientos in the North. Early types of *Triticites* and a fusulinid called *Wedekindellina* (or *Waeringella* according to Thompson) *ultimata*, which occur in the lower Missourian (Swope limestone) of Missouri and Kansas, are reported from this division.

Virgilian strata, characterized by considerable sandstone and red beds, contain advanced forms of *Triticites* and a fusulinid genus called *Dunbarinella*. These deposits, which are correlated with Shawnee and Wabaunsee formations of the northern Midcontinent, are separated from the overlying Abo sandstone (Permian) by a disconformity.

Colorado and southeastern Wyoming (Columns 42 to 44).—The Pennsylvanian col-

umns for this area were prepared by Williams using data from his field studies, notes submitted by Johnson and Condra, and incorporating information from other sources.

The Molas formation of southwestern Colorado consists mainly of unfosssiliferous red clay, indeterminate in age. It may be early Desmoinesian, instead of Lampasan, but is probably not older. The Hermosa formation contains numerous Desmoinesian species, including fusulinids such as *Fusulina meeki*, *F. rockymontana*, *F. minutissima*, *Wedekindellina coloradoensis*, and *W. excentrica*, bryozoans such as *Prismopora*, and brachiopods such as *Mesolobus mesolobus*, *Spirifer occidentalis*, and *Marginifera haydenensis* (Roth, 1934). *Chaetetes milleporaceus*, abundant in Marmaton beds of the northern Midcontinent but unknown from Missourian deposits, is also reported from the Hermosa of southwestern Colorado (Vanderwilt, 1935). Rocks called Rico formation overlie the Hermosa disconformably. They contain *Myalina* and other mollusks and some long-ranging brachiopods. The deposits called Rico seem mostly to be Lower Permian in age, but in places Williams has identified Pennsylvanian fossils near the base.

Pennsylvanian deposits of central Colorado are very thick. Little has yet been published showing subdivisions and zonation. Local names are applied in different ranges, as shown in the chart. Based largely on unpublished studies, some parts of these strata, such as the Glen Eyrie shale member of the Fountain formation near Colorado Springs, which has yielded numerous marine fossils, are classed as Morrowan in age. Undescribed Lower Pennsylvanian beds exposed in the Colorado River valley west of Minturn also carry Morrowan fossils, but in most places the lowermost Pennsylvanian is thought to be Lampasan or Desmoinesian. The lower part of the McCoy formation in central Colorado contains a Desmoinesian fauna, including *Fusulina distenta*, *F. rockymontana*, *Wedekindellina coloradoensis*, *W. euthysepta*, *Prismopora serrata*, *Mesolobus mesolobus*, and other forms (Roth and Skinner, 1930). Read (1934, p. 81) has described *Sphenopteris asplenioides*, *Neuropteris gigantea*, *N. heterophylla*, and several other fossil plants from Pennsylvanian strata called Weber(?) in the Mosquito Range, and this flora is interpreted as unquestionably Pottsville in age, probably middle Pottsville. Read thinks that plants from the Glen Eyrie shale are somewhat younger than the Weber(?) flora but also Pottsville. Johnson (1934) notes the absence of any physical sign of a break between central Colorado rocks identified as lower mid-Pennsylvanian and those containing Permian fossils. In places, beds classed as Maroon contain fossils indicating Pennsylvanian age.

Fusulinids and other marine fossils from precisely determined horizons in the Pennsylvanian section of the Hartville Uplift in southeastern Wyoming, as reported by Condra and Reed (1935), support recognition of Lampasan, Desmoinesian, Missourian, and Virgilian deposits in this region. No Morrowan beds are recognized. The oldest fossiliferous Pennsylvanian includes *Mesolobus mesolobus*, *Chaetetes*, *Spirifer occidentalis*, and other fossils that indicate Desmoinesian, or possibly Lampasan, age. Slightly higher strata contain *Wedekindellina*. Condra, Reed, and Scherer (1940) assign upper middle Hartville (Minnelusa) beds to the Missourian and Virgilian.

South Dakota (*Column 45*).—The lower part of the Minnelusa formation, exposed in the Black Hills Uplift, belongs to the zone of *Fusulinella* and may be classed as Lampasan. Thompson (1936) reports the occurrence of *Fusulinella dakotensis*, *F.*

furnishi, and *F. acuminata* from a zone about 150 feet above the base of the formation, and he states that these fossils are very closely related to *F. fittsi* and *F. prolifica* of the lower Atoka in Oklahoma, and *F. llanoensis* and *Fusiella primaeva* of the Big Saline group ("upper Marble Falls limestone") of Texas.

Desmoinesian fossils occur in the mid-portion of the Minnelusa formation. These include *Mesolobus*, *Chaetetes milleporaceus*, and *Spirifer rockymontanus*. The upper part of the formation probably contains Missourian and Virgilian deposits, as indicated by the presence of fusulinids identified in Upper Pennsylvanian rocks of the Hartville Uplift near the Black Hills. Paleontological evidence from the Black Hills region is indecisive. Condra, Reed, and Scherer (1940) identify divisions of the Minnelusa that correspond to groups defined in the Hartville area. Although paleontological evidence is lacking, they consider the uppermost part of the Minnelusa beds as Permian.

Northern Wyoming and southern Montana (*Column 46*).—The Bighorn Mountains and adjacent territory reveal Pennsylvanian deposits most of which are poorly fossiliferous. They have been studied little. The column for this district has been prepared by Williams. The term Amsden formation has been applied to strata now known to include both Mississippian and Pennsylvanian deposits, but C. C. Branson has proposed the name Sacajawea for Mississippian Amsden beds, restricting use of the latter name to Pennsylvanian strata. Whether the Amsden includes Morrowan and Lampasan deposits is not determined; no fossils indicating such age have been found. The Tensleep sandstone, which overlies the Amsden, is reported (Branson, 1939) to contain characteristic Desmoinesian shells such as *Mesolobus mesolobus*, *Spirifer rockymontanus*, *Fusulina*, and *Chaetetes milleporaceus*. No evidence of the presence of Missourian or younger Pennsylvanian rocks is offered.

Central and northern Montana (*Column 47*).—This column, also prepared by Williams, records the presence of Pennsylvanian deposits designated as the Quadrant formation. Scott (1935) states that the Tensleep sandstone grades laterally into the Quadrant quartzite, upper calcareous zones of the Tensleep being represented by nearly pure limestone beds in the upper part of the Quadrant. Williams considers the Quadrant to represent Desmoinesian and older Pennsylvanian deposits, but paleontological evidence is not adequately known.

Western Montana and northwestern Wyoming (*Column 48*).—The so-called Amsden occurs in part of this region, being overlain disconformably (Scott, 1935) by the Quadrant or Tensleep. The Quadrant formation contains *Wedekindellina* and *Fusulina* in this area, indicating middle Desmoinesian age. No Missourian fossils have been recognized.

Central and northern Idaho (*Column 49*).—The age span of Pennsylvanian deposits of this region is not yet satisfactorily determined. Girty (*in* Umpleby, Westgate, and Ross, 1930; Ross, 1934) records the presence of *Spirifer rockymontanus*, *Chaetetes milleporaceus*, *Mesolobus*, and *Fusulina secalica* near the base of the Wood River formation. These fossils (except "*F. secalica*", broadly identified) indicate Desmoinesian age. No proof of the existence of deposits representing Morrowan, Lampasan, Missourian, or Virgilian time is known in the Wood River or Blacklead limestones; Williams believes that Missourian and perhaps Virgilian deposits are represented.

Central and northeastern Utah, southeastern Idaho, and southwestern Wyoming

(*Column 50*).—The classification and correlation of Pennsylvanian rocks of this region are based on the literature and study by Williams. Knowledge of zonation is meager. Concerning the Wells formation in southeastern Idaho, Girty (1927) has expressed judgment that both Pottsville and post-Pottsville strata are represented. Beds of Desmoinesian age can be identified on the basis of reported occurrence of *Mesolobus, Marginifera muricatina,* amd *Fusulinella*. Partly on the ground of lithologic features and stratigraphic position, the Wells formation is considered to represent strata in Utah that have been called Weber, Morgan, and the lower part of the Park City formation. Beds in various places identified as lower Park City probably differ in age. Stewart Williams (1939) has collected Pennsylvanian fossils from so-called lower Park City deposits in the Uinta Mountains, whereas A. A. Baker and James Steele Williams (1940) have reported a Permian fauna in supposed lower Park City limestone in the Wasatch Mountains.

The Manning Canyon and Oquirrh formations, described in the Oquirrh Mountains, have been recognized by Baker and Williams (1940) in the Wasatch Mountains. The Manning Canyon is Mississippian in part and Pennsylvanian in part (Gilluly, 1934, p. 31), but recognition of series awaits study of collections obtained from northeastern Utah. The Oquirrh formation ranges from Desmoinesian or older to uppermost Pennsylvanian and probably Permian (evidence from larger fossils identified by Williams and fusulinids identified by Henbest, as reported by Baker and Williams, 1940).

Southern Utah and northern Arizona (*Column 51*).—Stratigraphic units in the Pennsylvanian of this area are correlated by Williams as shown in the chart. The Hermosa formation contains fossils of Desmoinesian age, as in the southwestern Colorado region. The Paradox formation, which underlies beds called Hermosa, may also be equivalent to part of the Hermosa. Baker, Dane, and Reeside (1933) report fossils that are not diagnostic as to age within the Pennsylvanian and conclude that the Paradox is probably mostly older than the Hermosa, being perhaps partly equivalent to the Molas or in part intermediate between Molas and Hermosa. Girty (Eardley, 1933) has identified fossils in the lower 7000 feet of Pennsylvanian beds in the southern Wasatch Mountains as belonging to Pottsville horizons, and post-Pottsville fossils are reported about 9000 feet above the base of the Pennsylvanian. No definite break between Pennsylvanian and Triassic is found, although Permian rocks have not been distinguished. Limestone in the Grand Canyon region that has been classed as upper Redwall rests disconformably on the Lower Mississippian true Redwall, and some of this limestone, to which Darton has applied the name Magdelena, may be Lower Pennsylvanian; in most places all the Redwall is Lower to Middle Mississippian. Some beds included in the Rico and Supai are probably Pennsylvanian, but these formations are identified as Permian in most places.

Central and southeastern Arizona (*Column 52*).—Columns for this region, prepared by Williams, indicate the presence of Desmoinesian and younger Pennsylvanian deposits. Stoyanow (1936) reports that basal beds of the Galiuro limestone contain abundant *Fusulinella* (which may signify Lampasan age), and upper strata of this formation yield *Mesolobus mesolobus, Chonetina flemingi, Spirifer rockymontanus, S. opimus, S. occidentalis,* and *Prismopora triangulata*. These fossils indicate an age not younger than Desmoinesian.

According to Stoyanow (1936), the lower part of the Naco limestone bears typical

Lower Pennsylvanian fossils, including *Chaetetes milleporaceus* and *Spirifer occidentalis*, along with others having long range. No Middle or Upper Pennsylvanian beds are recognized by Stoyanow but Williams has tentatively identified Late Pennsylvanian fossils from the Naco in the Tombstone area. Locally, the Naco rests on Upper Mississippian rocks (Hernon, 1935, p. 666).

GREAT BASIN AND PACIFIC BORDER REGION

Western and southwestern Utah (*Column 53*).—Two stratigraphic sections have been prepared by Williams to show Pennsylvanian rocks of this area, which includes the type region of the Manning Canyon and Oquirrh formations. The Manning Canyon is a mappable unit that contains both Mississippian and Pennsylvanian faunas. It is overlain by the thick Oquirrh deposits, which yield typical Desmoinesian fossils near the base (Girty, *in* Gilluly, 1932) and Late Pennsylvanian or Permian fossils near the top in some places. Desmoinesian genera represented in the Oquirrh include *Mesolobus* and *Prismopora*. The distinctive bryozoan *Archimedes*, which commonly is thought to be restricted to Mississippian horizons, here occurs in unquestionable primary association with Desmoinesian fusulinids and other fossils (Gilluly, 1932).

The Elephant limestone and Talisman quartzite are typically exposed in the San Francisco mining district. Few identified fossils have been reported from the former, and none from the latter. The Elephant limestone is undoubtedly mainly Pennsylvanian but may be Permian in part. The Topache limestone, beneath the Talisman, may contain beds of Pennsylvanian age, but known identifiable fossils seem to be Late Mississippian.

Nevada (*Colums 54*).—The stratigraphic summary of Pennsylvanian deposits in Nevada, as shown by Williams on the chart, distinguishes six districts, but paleontologic data are fragmentary in all of them. For example, the Bailey Spring limestone, which occurs in the Pioche district, is only vaguely classified (Westgate and Knopf, 1932) as Mississippian and Pennsylvanian, on the basis of fossils identified by Girty. Some beds of this formation contain brachiopods called *Diaphragmus elegans*, *Avonia* aff. *A. arkansana*, *Cliothyridina sublamellosa*, and other fossils that suggest Upper Mississippian, whereas other horizons have yielded forms identified as *Chaetetes milleporaceus*, *Hustedia mormoni*, *Marginifera splendens*, and *Fusulina*, which are assuredly Pennsylvanian, probably Desmoinesian.

In southern Nevada, Longwell and Dunbar (1936) have differentiated the thick Bird Spring formation into parts respectively belonging to the Upper Mississippian, Lower Pennsylvanian (zone of *Fusulinella*), Upper Pennsylvanian (zone of *Triticites*), and Permian (zone of *Schwagerina*). The zone of *Fusulinella* is presumably Lampasan in age, but Desmoinesian strata may be present in the Lower Pennsylvanian. Differentiation of the zone of *Triticites* into Missourian and Virgilian is not indicated.

Pacific Border (*Columns 55 to 58*).—Pennsylvanian rocks of California, Oregon, Washington and Alaska are little known. Several columns prepared by Williams indicate names that have been applied to rocks presumed to belong to this division of the geologic succession. Some supposed Pennsylvanian is now identified as Permian on the basis of fusulinid evidence. In central Oregon, Read and Merriam (1940) have recently reported the occurrence of about 3000 feet of clastic deposits to which the name Spotted Ridge is applied. These rocks rest on Upper Mississippian strata containing *Striatifera* and *Gigantella* and underlie beds having a marine fauna identi-

fied as Permian. The clastic deposits contain *Sphenopteris, Dactylotheca, Phyllotheca,* and *Dicranophyllum,* which are interpreted to indicate early Pennsylvanian age, although not certainly.

The Bird Spring and Monte Cristo deposits in California are described by Hazzard (1937). A section for the Inyo Range has not been included in the chart, although work by L. F. Noble and others now in progress indicates presence of Pennsylvanian beds in this region. Also, deposits of northern California that are possibly Pennsylvanian are omitted from the chart.

The age of Alaskan deposits of supposed Pennsylvanian age is very uncertain. The Nation River formation is largely terrigenous in origin and has yielded no marine invertebrates. The few fresh-water fossils and plants known are not diagnostic. The "limestones of Soda Bay" are strata studied by Williams in southeastern Alaska that, on the basis of incomplete fossil evidence, he thinks belong to the Pennsylvanian.

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STRATIGRAPHY AND VERTEBRATE PALEONTOLOGY OF PLEISTOCENE DEPOSITS OF SOUTHWESTERN KANSAS

BY CLAUDE W. HIBBARD

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ABSTRACT

The stratigraphy and vertebrate fossils of the Meade and Kingsdown silt formations of southwestern Kansas are discussed. Correlations are made with other deposits in Kansas and Oklahoma.

Four local faunas are recognized in the Meade formation. The Cudahy, Tobin, and Wilson Valley faunas are considered as contemporaneous and occur in the Meade formation just below the Pearlette ash member.

The Cudahy fauna, a glacial assemblage of invertebrates and vertebrates, is reported for the first time. The mammals recovered consist of 12 genera and 11 species. One genus and 8 species are described as new.

The Kingsdown silt formation is divided into the lower and upper Kingsdown on the basis of lithology and associated vertebrate fossils. The characters of the deposits and the mammalian fossils taken from them are discussed.

INTRODUCTION AND ACKNOWLEDGMENTS

The Pleistocene deposits of the "High Plains" region, especially those of western Kansas, have generally been considered as the "*Equus* beds" or "Sheridan beds."

They range from the oldest Pleistocene to beds of post-Pleistocene age. Cragin (1896, p. 53) described three Pleistocene formations in Clark and Meade counties, Kansas. From recent studies it has been possible to extend certain of his formations and to clarify some of the questions concerning the deposits that have yielded fossils in the past. Many vertebrate fossils from these deposits were discussed by Hay (1924), who assigned some of them to the various glacial and interglacial stages which have been described in the upper Mississippi Valley region. It is impossible to confirm his correlations, however, because of our inadequate knowledge of the stratigraphic relationship of the nonglacial deposits southwest of the ice border to the known glacial deposits northeast of this area and because of the scarcity of vertebrate fossils in the upper Mississippi Valley Pleistocene deposits.

Acknowledgment is made to the Geological Society of America for a grant from the Penrose Bequest which was used to help defray field expenses, and to the members of our field parties for their assistance and untiring interest shown in collecting the fossil material which forms the basis of this report. They received no compensation except the pleasure derived from their work. I am further indebted to John C. Frye, H. T. U. Smith, and Bruce F. Latta who have contributed freely of their time to examine deposits in the field and to discuss the existing problems of the area under study.

AREA AND OBJECT OF STUDY

The areas studied lie chiefly in the northern half of Clark, western Kiowa, northwestern Comanche, Meade, eastern Seward, southeastern Grant, a local area in Russell and Lincoln counties, Kansas, and a locality in the northern part of Beaver County, Oklahoma. A reconnaissance had been made through these counties prior to 1942, and Meade County had been intensively studied.

The object of field work in 1942 was to correlate, insofar as possible, the Pleistocene beds of Clark County with the better-known deposits of Meade County. Vertebrate remains were discovered by A. B. Leonard and George C. Rinker at the base of the volcanic ash in Meade County while washing the matrix taken there for the recovery of invertebrates. This led to the intensive study of the silts directly below the volcanic ash deposits in southwestern Kansas and to the recovery of additional vertebrate remains. These fossils establish the age of the ash and make possible the use of this bed as a stratigraphic marker.

MEADE FORMATION

GENERAL CONSIDERATIONS

The Meade formation was first recognized and described by Cragin (1896, p. 53) as "The Meade Gravels". The name was proposed for the lowest of three "terranes" that occur in the immediate vicinity of the old Vanhem post office in Clark County in sec. 13, T. 30 S., R. 23 W. These beds continue westward and are well exposed south of Meade Center, Kansas, for which they were named. The town is now known as Meade, in Meade County, Kansas.

Cragin made the following statement in regard to the formation:

"... the lowest (terrane) consists of the ancient (supposed late Pliocene) gravels and sands laid down in deep, broad valleys, ... where they constitute the artesian-water-holding formation. They contain abundant remains of horses, llamas, elephants, turtles, etc., and rarer remains of *Megalonyx* and *Felidae*, ... indicating the fauna of the *Equus* beds. These gravels are mostly unconsolidated, but frequently contain hard ledges in Meade county and elsewhere, ... and frequently grade into the Pearlette (volcanic ash)."

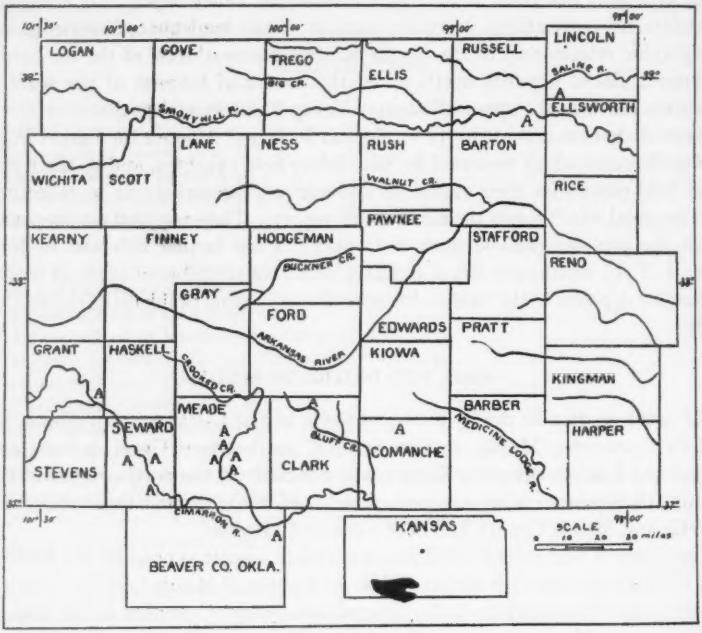

FIGURE 1.—*Location map of area studied*

Localities in which studies were made are shown in black on small Kansas outline map. Known exposures of Pearlette ash are indicated by (A) on detailed map.

As will be shown later, Cragin confused in part the lower gravels and sands of his "Meade gravels" with a much younger channel phase in sec. 17, T. 32 S., R. 28 W., in Meade County, Kansas.

Hay (1917, p. 39–58) described the material collected by Cragin in 1891 from Clark and Meade counties. Hay assigned all the fossils collected by Cragin to the "Meade gravels" on the basis of data left by Cragin. All the material reported by Hay, except *Hipparion cragini* and the maxillary of *Equus leidyi*, was taken from a channel deposit of coarse to fine sand in sec. 17, T. 32, S., R. 28 W., in Meade County. This channel phase is younger than the "Pearlette ash" and is not equivalent to the basal "Meade gravels" as supposed by Cragin. Topographically these channel deposits are lower than the ash deposit just east of this locality on the east side of

FIGURE 1.—RIPPLE MARKS IN PEALETTE ASH OF MEADE COUNTY.
Photograph by V. C. Fishel.

FIGURE 2.—STRIATED PEBBLE
From the basal Meade formation of Meade County.

RIPPLE MARKS AND STRIATED PEBBLE

FIGURE 1.—MOLAR OF *Stegomastodon mirificus* (Leidy).
From Meade formation of Clark County. Photograph by V. C. Fishel.

FIGURE 2.—COBBLES OF SCORIACEOUS BASALT
From "High Terrace" deposits along the Cimmaron Valley. Photograph by J. C. Frye.

FIGURE 3.—CONSOLIDATED SAND AND GRAVELS OF THE MEADE FORMATION IN CLARK COUNTY

MASTODON MOLAR, SCORIACEOUS BASALT, AND CONSOLIDATED SAND AND GRAVELS

Crooked Creek. This relationship of the beds may have confused Cragin in his study of this area. The topographic position of this deposit is accounted for by the Crooked Creek fault (Frye, 1942, p. 24, Fig. B).

Smith (1940, p. 100–108) was unable to recognize Cragin's "Meade gravels". The evidence from the fossils available at the time of his study was scant, and the relationships of the deposits were obscured by the faulted beds and local sinkhole fills. Smith recognized Cragin's Kingsdown formation and named and described the "Odee formation" which he considered to be of early Pleistocene age. He also applied the name "*Equus niobrarensis* beds" to four widely separated fossiliferous Pleistocene deposits and "Jones Ranch beds" to a local sinkhole fill in Meade County.

Smith's "Odee formation" is not thoroughly understood since the deposits are chiefly local sinkhole fills, and to date only fragmentary fossils are known from these deposits. Some of the exposures designated by Smith may be equivalent in age to part of the Meade formation, but most of them are younger and equivalent to some phase of the Kingsdown silt. Apparently the diatomaceous marl mentioned by Cragin as occurring above the "Kingsdown Marl" was included by Smith in his "Odee formation".

In regard to Smith's "*Equus niobrarensis* beds" in Meade County, his deposit No. 1 in the NE¼, sec. 33, T. 32 S., R. 29 W., is an exposure of the basal sand and gravel of the Meade formation unconformably overlying the Rexroad member of the Ogallala. His localities Nos. 2 and 3 are equivalent in age and are deposits of a younger channel phase belonging above the "Pearlette ash" of the Meade formation. Locality No. 4 is a local sinkhole fill, and the horizon producing the *Equus* remains may be equivalent in age to his localities Nos. 2 and 3. Smith's "*Equus niobrarensis* beds" are probably equivalent in part to a phase of the lower Kingsdown. The occurrence of *Paramylodon harlani* (Owen) found in both the lower Kingsdown of Clark County and the channel deposits from which the Cragin Quarry fauna was taken in Meade County indicates deposits of the same age.

The "Jones Ranch beds", named by Smith, were deposited in a local sink. These sinkhole deposits, which have been dissected to a depth of 60 feet, apparently range from early to late Pleistocene. One of the youngest beds near the top of this exposure yielded the Jones fauna. It is now believed that the Jones fauna and the bed in which it occurs is possibly equivalent to the basal phase of the upper Kingsdown silt.

Frye and Hibbard (1941b, p. 411–419) redefined the Meade formation to include Cragin's "Meade gravels" at the base, Cragin's "Pearlette ash", Smith's "Odee formation", "*Equus niobrarensis* beds", and "Jones Ranch beds", and all other beds of Pleistocene age above the Rexroad member of the Ogallala formation and below the Kingsdown silt.

Further study in Meade County and surrounding areas, since the Meade formation was redefined by Frye and Hibbard, has furnished more data on the Meade formation which is here presented.

The best known exposure of the Meade formation is at the type locality. The following measured section at this locality is taken from Frye (1942, p. 98):

SECTION OF MEADE FORMATION

Sec. 21, T. 33 S., R. 28 W. Meade County

	Thickness (Feet)
19. Topsoil	0.5
Meade Formation	
18. Silt, sand, and some clay, tan to buff-brown massive, contains sandy beds and caliche cobbles	14.8
17. Sand and silt, gray to gray tan	5.4
16. Clay with some silt and sand, light gray, massive. Breaks with a concoidal fracture when dry	4.5
15. Volcanic ash, pearl gray, lenticular, somewhat impure	1.6
14. Silt, clay, and some sand, gray, massive, contains a few calcareous nodules, (Borchers fauna, where present, occurs at top of this bed)	6.4
13. Volcanic ash (Pearlette member), pearl gray, thin-bedded and cross-bedded	7.1
12. Clay, silt, and some sand, tan-gray and brown-gray, massive. Grades upward into yellowish gray-green sand and contains some mottled yellow-brown silt. Contains a few thin beds of ash and calcareous nodules, (Cudahy fauna occurs at top of this bed, where present)	9.5
11. Sand, silt, and coarse gravel, brown, contains abundant nodules. Grades upward into red-brown to tan-maroon sand and silt	8.8
10. Sand, coarse and well sorted at base, grading upward into finer, more poorly sorted sand. Calcareous nodules at top	10.1
Unconformity	
Ogallala formation	78.0
Total thickness exposed	146.7

The best westerly exposure of the Meade formation studied occurs on the south side of the Cimarron River in Seward County, southeast of Arkalon. Along the valley wall is exposed the Meade formation unconformably overlain by younger terrace deposits and unconformably underlain by older beds of undetermined age. A measured section is as follows:

SECTION OF MEADE FORMATION AND ASSOCIATED BEDS

NW¼, Sec. 35, T. 33 S., R. 32 W., Seward County

	Thickness (Feet)
QUATERNARY	
11. Top soil	0 to 2.0
10. High terrace gravel, poorly sorted sand and gravel, pebbles range up to more than 7 inches in largest diameter. Pebbles include various rock types such as pink granite, felsite, scoriaceous basalt (Pl. 2, fig. 2), quartzite, sandstone, and chert. Unconformity at base. (Locally obscured by dune sand)	12.0
Meade Formation	
9. Clay, silty, gray to light tan, (*Equus* remains) and fine sand interbedded, and interbedded and intermixed with volcanic ash. Extreme lateral variation	10.0
8. Sand, fine, massive, pale buff and silt grading upward into medium and coarse sand, becoming fine at top	5.0
7. Silt and clay, thin-bedded	2.2
6. Sand and gravel grading upward into well-sorted medium sand	8.0
5. Sand and gravel tightly cemented with calcium carbonate	1.2
4. Sand and gravel, cross-bedded, pebbles of pink quartzite, and various igneous rock types, ranging in diameter up to 2 inches, (*Equus cumminsii*)	3.3
Disconformity	
PLIOCENE OR PLEISTOCENE	
3. Sand and silt, tan and dull pink, poorly sorted scattered nodules and bands of caliche	5.2

FIGURE 1.—CROSS-BEDDED, CONSOLIDATED SAND AND GRAVEL OF THE MEADE FORMATION IN MEADE COUNTY. Photograph by J. C. Frye

FIGURE 2.—UNCONSOLIDATED SAND AND GRAVEL OF THE MEADE FORMATION IN CLARK COUNTY

SANDS AND GRAVELS OF THE MEADE FORMATION

2. Silt and clay, gray and tan with bands of nodular caliche with a massive caliche zone at top	2.6
1. Sand, silty, buff tan to gray	8.1
Base of exposure covered with alluvium and slump	
Total thickness exposed	59.6

BASAL SAND AND GRAVEL OF THE MEADE FORMATION

Description.—These beds are generally cemented and show considerable cross-bedding. One of the best exposures of the cemented sand and gravel in Meade County is in sec. 9, T. 33 S., R. 29 W. (Pl. 3, fig. 1), where they are channeled into the underlying Rexroad member of the Ogallala formation. At many places in the sand and gravel there are local deposits of manganese. Many of the fossils found in these deposits in Clark County are stained black from the manganese. These sand and gravel deposits are nowhere exposed in northeastern Meade County. In Clark County, however, they are exposed along tributary streams on the north side of Bluff Creek south of Bloom, Kansas. A typical exposure is in sec. 17, T. 30 S., R. 23 W., along a small tributary of Bluff Creek on the Taylor ranch where these beds underlie the lower Kingsdown silt. Eastward across Clark County along the north side of Bluff Creek the exposures of the basal sand and gravel become more numerous and thicker. They are both uncemented and cemented. In this area the vertebrate remains are most abundant.

Along the west and east forks of Fish Creek in Clark County are good exposures of the cemented basal sand and gravel (Pl. 2, fig. 3) channeled into older beds that may be of Rexroad age. A measured section is as follows:

SECTION OF MEADE FORMATION (IN PART)

SW¼, sec. 23, T. 30 S., R. 22 W., Clark County

	Thickness (Feet)
QUATERNARY	
7. Top soil	2.0
Meade Formation	
6. Sand and gravel	23.6
5. Sand, fine, and small pebbles of reworked Ogallala, cross-bedded and cemented	6.0
4. Sand and gravel	10.0
3. Sand, fine, silty, interbedded with lenses of fine sand, locally cemented	6.0
Disconformity	
PLEISTOCENE OR PLIOCENE	
2. Clay, gray with caliche zones, basal 2 feet contains blocks of caliche and reworked invertebrates from the Cretaceous	9.3
CRETACEOUS	
1. Sand, fine, yellow, streaked with red	2.0
Total thickness exposed	58.9

SECTION OF BASAL MEADE SAND AND GRAVEL (IN PART)

SE¼, sec. 26, T. 30 S., R. 22 W., Clark County

	Thickness (Feet)
QUATERNARY	
3. Top soil	2.0

Meade Formation	
2. Sand and gravel, cemented, cross-bedded containing some reworked Cretaceous at base	6.0
(?) Ogallala (Rexroad member)	
1. Silt, fine sandy, red to pinkish buff, containing much lime, with reworked calcium carbonate concretions near top. Top of bed just below unconformity leached. Base not exposed	16.0
Total thickness exposed	24.0

The maximum thickness of the basal sand and gravel of the Meade formation was observed along the eastern Clark County line in the NW¼, sec. 19, T. 30 S., R. 20 W., in Kiowa County where they reach a thickness of 50 feet. These beds were laid down by a large through-flowing stream. Whether the sand and gravel west of this exposure in Clark County were laid down by the same stream and are exposed only along the edge of the channel where it shifted laterally across its flood plain, or whether they belong to a tributary, is not known. Flood-plain and upland deposits equivalent in age to the basal sand and gravel have not as yet been recognized.

The foregoing discussion of the deposits of the Meade formation apply to the exposures in southwestern Kansas and the Oklahoma Panhandle, and in particular to the area drained by the Cimarron River. North of the Arkansas River deposits herein correlated with the Meade formation consist of a terrace deposit only along the Smoky Hill River valley and fillings in a high level abandoned valley (Frye *et al.*, 1943). In the Smoky Hill and Saline River drainage basins these deposits attain a maximum thickness of 75 feet. In this area the upland surface is mantled by Tertiary sediments overlying Cretaceous rocks, and the area of Pleistocene outcrop is sharply defined by the Cretaceous valley walls.

An exposure of these beds presumably deposited by a stream, tributary to the major valley, occurs in sec. 35, T. 14 S., R. 11 W., in Russell County. A measured section after Frye *et al.* (1943, p. 38) is as follows:

MEASURED SECTION OF MEADE FORMATION

In sec. 35, T. 14 S., R. 11 W., Russell County

	Thickness (Feet)
QUATERNARY	
6. Sand, silt, and gravel. Irregularly bedded, poorly sorted gravel at base, composed dominantly of abraded Cretaceous rocks, interbedded with sand, silt, and clay, becoming finer upward. Upper part sand and silt tan to brown. Irregularly bedded to massive, with bands of caliche nodules. Upper part of interval partly covered	20.0
5. Sand, fine, and silt thin and even bedded with lenses of sand, tan to buff. Contains vertebrate fragments and a few invertebrates throughout. Erosional surface at base (disconformity)	10.6
Meade formation	
4. Volcanic ash, Pearlette member of Meade formation, (in a distance of 50 yards westward, thickness increases to 2 feet)	0.2
3. Silt and fine sand, gray to greenish gray with thin beds of sandy clay. Terrestrial snails occur in the basal 5.5 feet, aquatic snails occur in upper 1 foot, vertebrate remains throughout. (Tobin fauna, equivalent to Cudahy fauna)	6.5
2. Sand and gravel, cross-bedded, interbedded with thin lenses of silt and zones of abraded Cretaceous limestone pebbles. Cobbles up to 0.7 foot in diameter. Vertebrate fragments	3.9

CRETACEOUS	
1. Shale and siltstone of the Dakota group, to level of Smoky Hill River flood plain..	40.0
Total thickness exposed.....	81.2

An exposure of these Pleistocene deposits underlying the floor of the Wilson Valley, which formerly was occupied by the Pleistocene Saline River occurs in secs. 27 and 28, T. 13 S., R. 10 W., Lincoln County. Following is a measured section after Frye *et al.* (1943, p. 39).

MEASURED SECTION OF MEADE FORMATION

In sec. 28, T. 13 S., R. 10 W., Lincoln County

	Thickness (Feet)
QUATERNARY	
3. Sand, fine, thin-bedded to laminated, grades upward into massive silt and fine sand, less sandy toward top, tan to reddish buff. Caliche nodules are distributed throughout the upper half.....	27.0
Meade formation	
2. Volcanic ash (Pearlette member), thin-bedded, upper part interbedded with fine sand. Upper part of interval partly covered.....	7.0
1. Sand and silt, gray, grading upward into gray sandy, silty clay. Upper 18 inches contains rich molluscan fauna and associated vertebrates (Wilson Valley fauna, equivalent to Tobin and Cudahy faunas). Base of section at creek level.....	11.0
Total thickness exposed.....	45.0

Vertebrate fossils from the basal sand and gravel of the Meade formation.—The vertebrates taken from the basal sand and gravel of the Meade formation in Seward, Meade, and Clark counties, Kansas are not well enough known to be treated as a fauna. They constitute an assemblage of upper Pliocene and early Pleistocene mammals rather than a contemporaneous group.

The vertebrate remains from these deposits are fragmentary and are best known from the Pyle ranch (formerly known as the Stephenson ranch) in Clark county, especially from exposures in secs. 12 and 13, T. 30 S., R. 23 W.

Phylum CHORDATA

Subphylum VERTEBRATA

Order PROBOSCIDEA

Family STEGOMASTODONTIDAE

Stegomastodon mirificus (Leidy)

(Plate 2, figure 1)

Mastodon mirificus LEIDY, 1858, Acad. Nat. Sci. Philadelphia, Pr. vol. 10, p. 10.

Fragmentary remains of this short-jawed mastodon are common on the north side of Bluff Creek in Clark County, where the basal Meade sand and gravel are exposed. Five disintegrated skulls were observed in the summer of 1936 as well as numerous parts of lower jaws and teeth. Only one complete tooth has been recovered from the deposit. It was identified by Dr. Edwin H. Colbert of the American Museum.

Order PERISSODACTYLA

Family EQUIDAE

Nannippus phlegon (Hay)

(Fig. 2G, H, I)

Equus phlegon HAY, 1899, Am. Geol., vol. 24, p. 345.
Hipparion cragini HAY, 1917, Kansas Univ. Sci. Bull., vol. 18, no. 2, p. 42–43.

A RP_2, No. 3966, of this little horse, was collected in Clark County, in 1936, and a left lower premolar or molar, No. 6517, was found in 1942. Both teeth, taken in sec. 18, T. 30 S., R. 22 W., show considerable weathering and some evidence of reworking and are believed to have been redeposited from the upper Pliocene. Deposits of unknown age, though younger than the middle Pliocene, occur in Clark County into which the Meade sand and gravel are channeled. These beds may have been a source for the older fossils.

Cragin collected an upper molar or premolar on the Thomas Ranch, on Bluff Creek in 1891 (From a letter by M. M. Mayse, County Engineer, "The only Thomas land that I have been able to locate in Clark county is the $SW\frac{1}{4}$, sec. 36, T. 30 S., R. 24 W."). This ranch is located in the headwaters of Bluff Creek. The tooth was described by Hay (1917, p. 42) as *Hipparion cragini*. The characters of this tooth are the same as those of *Nannippus phlegon* (Hay) from the Blanco deposits of Texas.

Equus (*Plesippus*) *simplicidens* Cope

(Fig. 2B, F)

Equus simplicidens COPE, 1892, Am. Philos. Soc., Pr., vol. 30, p. 124.

In the collection there are a few isolated teeth of this horse and part of a right ramus, No. 3963, bearing DP_2-DP_4. The ramus was collected in 1936 in sec. 13, T. 30 S., R. 23 W. The specimen is badly worn and is believed to have been redeposited in the sand and gravel. On the basis of this specimen and the RP_2 of *Nannippus phlegon* I interpreted these beds as being upper Pliocene. They were so recognized by Smith (1940, p. 96) as corresponding to his Rexroad formation of Meade County on the basis of my identification. A LM^3, No. 6520, taken from the sand in sec. 12, T. 30 S., R. 23 W., in Clark County is smaller than *E. simplicidens* and slightly larger than that tooth of *E. cumminsii* Cope. The tooth is 72.0 mm. long and has a transverse width of 22.5 mm. The protocone has a length of 13.5 mm. The posterior border of the tooth is lacking. A right metacarpus, No. 6518, belonging to one of the smaller horses was found associated with the above tooth. Its overall length is 226.1 mm.

Equus (*Plesippus*) cf. *cumminsii* Cope

(Fig. 2A, D)

Equus cumminsii COPE, 1893, Texas Geol. Survey, 4th Ann. Rept. p. 67.

A right lower jaw, No. 6021, which appears to belong to this species of horse was collected from the basal sand and gravel of the Meade formation in the Arkalon gravel pit in Seward County. The jaw contains P_2-M_3. The anteroposterior diameter of the series is 122.4 mm. The depth of the jaw below P_4 measured on the labial side is 81.5 mm. Also taken from the same deposit is a LM^3, No. 6496, which has an anteroposterior diameter of 22.3 mm. and a transverse diameter of 17.9 mm. The length of the tooth is 68.8 mm.

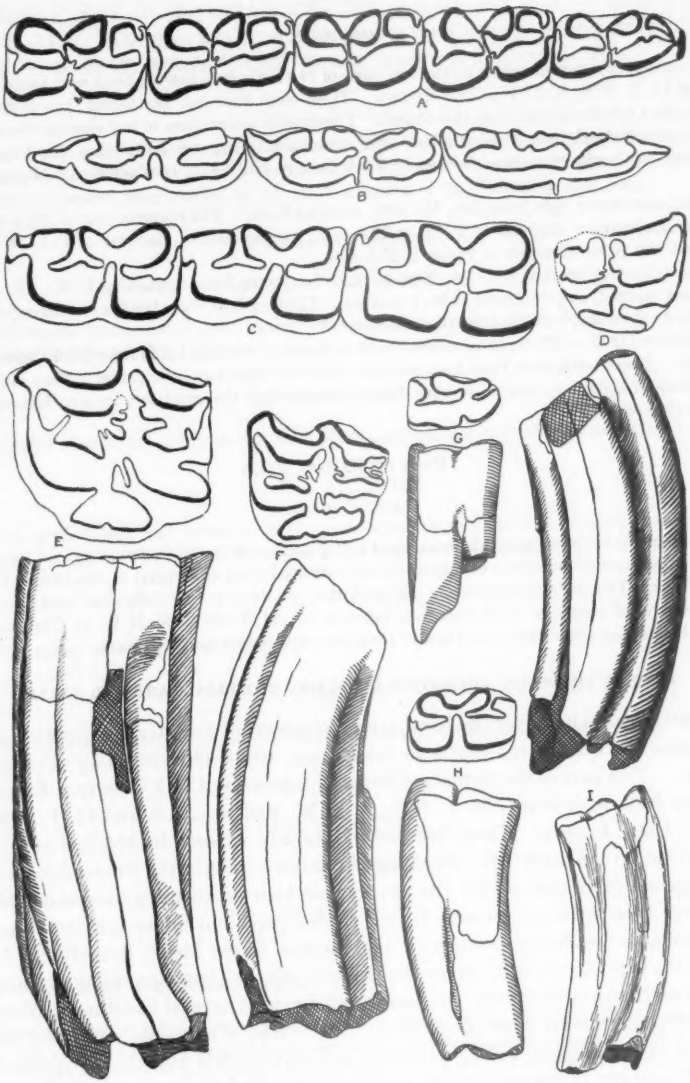

FIGURE 2.—*Teeth of* Equus *and* Nannippus

(A) *Equus* (*Plesippus*) cf. *cumminsii* Cope. KUMVP 6021, left ramus, P_4-M_3. Occlusal view. ×.87 approx. (B) *Equus* (*Plesippus*) *simplicidens* Cope. KUMVP 3963, right ramus, DP_2-DP_4. Occlusal view. ×1. (C) *Equus* sp. KUMVP 3961, right ramus, P_4-M_2. Occlusal view. ×1. (D) *Equus* (*Plesippus*) cf. *cumminsii* Cope, KUMVP 6496, LM^1. Lingual and occlusal views. ×1. (E) *Equus* sp. KUMVP 6521, left molar or premolar. Lingual and occlusal views. ×1. (F) *Equus* (*Plesippus*) sp. KUMVP 6520, RM^3. Lingual and occlusal views. ×1. (G) *Nannippus phlegon* (Hay). KUMVP 3966, RP_3. Labial and occlusal views. ×1. (H) and (I) *Nannippus phlegon* (Hay). KUMVP 6517, left lower premolar or molar. Labial, lingual, and occlusal views. ×1.

Equus sp.

(Fig. 2C, E)

A number of upper and lower molars and parts of two lower jaws bearing teeth were found in secs. 12 and 13, T. 30 S., R. 23 W., Clark County. These teeth show less weathering than do the teeth of the other horses reported from this deposit. I hesitate to assign them to any speecies though they are more advanced than *E. simplicidens* and *cumminsii*. They are larger than the horse teeth collected by Cragin from these deposits in Clark County which Hay considered to be *Equus leidyi* Hay.

The fragmentary right lower jaw, No. 3961, contains P_4-M_3. The posterior part of M_3 is missing. The anteroposterior diameter of P_4-M_2 is 99.4 mm.; anteroposterior diameter of P_4 is 31.5 mm.; greatest transverse diameter of crown is 23.2 mm.

The other fragmentary jaw, No. 3964, is that of a young horse containing P_3-M_2. P_2 and P_4 have not erupted, and the crown of M_2 is unworn. The length of M_1 is 108.0 mm.; anteroposterior diameter, 33.5 mm.; and the transverse diameter, 17.3 mm.

Williston (1898, p. 92) reported several teeth of *Equus occidentalis* Leidy from Bluff Creek, Clark County. These teeth must have been collected from the basal sand and gravel. They are not in the Museum collection, and no further data exist regarding the exact locality and horizon from which they were taken.

Order ARTIODACTYLA

Family CAMELIDAE

The remains of camels from the basal sand and gravel are rare and fragmentary. A large fragmentary metapodial was recovered from the consolidated sand and gravel in the Meade County State Park. This bone corresponds in size with that of *Camelops*. A radius and ulna, No. 6714, with an over-all length of 471.0 mm. were taken in sec. 24, T. 30 S., R. 21 W. in Clark County. These limb bones are smaller than those of *Camelops* previously taken in Kansas.

BEDS OF THE MEADE FORMATION OVERLYING THE BASAL SAND AND GRAVEL

Description.—Overlying the basal sand and gravel of the Meade formation in the type area are beds of red-brown to tan-maroon sandy silt containing calcium carbonate. This part of the formation is poorly exposed in Clark County. Exposures of these beds occur in sec. 14, T. 30 S., R. 22 W., and secs. 2, 8, and 11, T. 30 S., R. 21 W., Clark County. These beds are extensively exposed in Meade County and should not be confused with older beds of the same color in the Rexroad member of the Ogallala formation or with the younger red beds constituting local sinkhole fills.

Above these beds are massive tan-gray, blue-gray, and brown-gray clay and silt that underlie the Pearlette (volcanic ash) member of the Meade formation. At the top of the silty clay directly below the volcanic ash the abundant remains of invertebrates and associated vertebrates have been found at several localities. Wherever invertebrate remains were observed in these beds, subsequent collecting yielded remains of vertebrates. This vertebrate and invertebrate assemblage constitutes a new Pleistocene fauna and is here designated the Cudahy fauna for the locality at which it was first found in Meade County, Kansas.

Cudahy fauna.—This local fauna is a contemporaneous association of invertebrates and vertebrates found in silt directly below the volcanic ash in Meade County, Kansas, in secs. 2, 11, 12, and 13 T. 31 S., R. 28 W.; sec. 33, T. 31 S., R. 28 W.; and

sec. 26, T. 32 S., R. 28 W.; and Clark County, Kansas, secs. 1, 8, 11, 12, and 17, T. 30 S., R. 23 W. The type locality of the fauna is the Cudahy volcanic ash pit in sec. 2, T. 31 S., R. 28 W., Meade County, Kansas, known as locality No. 10.

Phylum MOLLUSCA

There are, in many places immediately below the Pearlette ash deposits in Meade County, abundant remains of mollusks with which the remains of vertebrates are found. The mollusks of this fauna are at present being studied by Dr. A. B. Leonard of the University of Kansas.

Phylum CHORDATA

Subphylum VERTEBRATA

A systematic description is given of the mammalian fauna only, though the occurrence of other vertebrates is here noted.

Class PISCES

A number of small fish vertebrae and a few pharyngeal bones with teeth were recovered.

Class AMPHIBIA

Limb, girdle bones, and vertebrae were found belonging to a small salamander and to frogs. These are being studied by Dr. E. H. Taylor of the University of Kansas.

Class REPTILIA

Small snake vertebrae were recovered.

Class AVES

Numerous fragmentary bird bones were found associated with the other vertebrates.

Class MAMMALIA

Order INSECTIVORA

Family SORICIDAE

Sorex cinereus Kerr

(Fig. 3)

Sorex cinereus KERR, 1792, Animal Kingdom, p. 206.

Thirty-one rami of a small *Sorex* belonging to the *cinereus* group, all bearing at least one molar, some with complete molar series, and one, No. 6631, with P_3-M_3, were recovered from below the ash. Twenty of the rami were taken at Locality No. 17, eight at Locality No. 10, and three at Locality No. 20 in Meade County.

All the rami and the dentitions are alike except No. 6576 from Locality No. 17, and No. 6631 from Locality No. 20 which are slightly larger than the others, being the size of a recent specimen of *S. c. cinereus* from Cheboygan County, Michigan. They possess a mental foramen that is located more posteriorly than in the other specimens or in the specimens of *Sorex cinereus* taken in association with the Jones fauna, a much younger Pleistocene fauna from Meade County, Kansas.

These are the oldest *Sorex cinereus* known from Kansas. The recent form is not known from Kansas. The present range of the species is from the Atlantic on the east to the Pacific on the west and approximately between 41° and 70° N. Lat., with their range fingering down the Rocky and Appalachian mountains approximately to the 35° N. Lat.

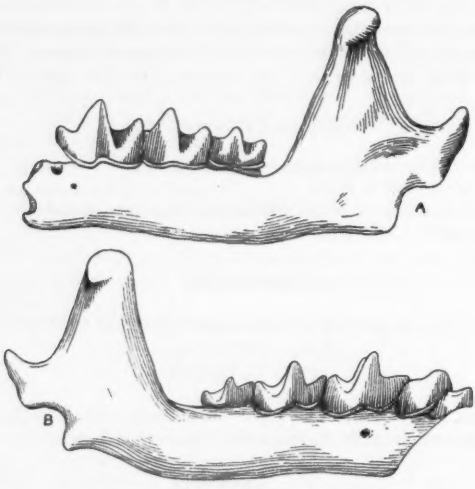

FIGURE 3.—*Ramus of* Sorex cinereus Kerr

(A) KUMVP 6512. Lateral view of left ramus. (B) KUMVP 6631. Lateral view of right ramus. ×10

Whether more than one species of the *Sorex cinereus* group occurred in Kansas at the time the fossils were deposited cannot be determined. The differences shown by the jaws may be due either to individual variation or to the fact that they are distinct forms. During certain stages of Pleistocene glaciation there occurred a severe crowding together of forms that would never occur together under normal conditions. If complete specimens of the fossil forms existed they would probably represent distinct races from those found living today.

Sorex cudahyensis n. sp.

(Fig. 4)

HOLOTYPE: No. 6513, Kansas University Museum of Vertebrate Paleontology, part of right ramus bearing P_4-M_2. Paratype No. 6581, right ramus bearing M_1-M_2, from the type locality. Collected summer of 1942 by Claude W. Hibbard and party.

HORIZON AND TYPE LOCALITY: Pleistocene, Meade formation, Meade County, Kansas, Locality No. 17, Cudahy fauna.

DIAGNOSIS: A shrew approximately the size of *Sorex merriami* Dobson; distinguished from other fossil and recent forms by the development of P_4. P_4 is robust and lacks both a depression on the lingual side and a small anterior cusp in front of the principal cusp. Cingulum along labial border of P_4 broad and heavy.

DESCRIPTION OF HOLOTYPE: Fragmentary right ramus bearing P_4-M_2. P_4 has a heavy cingulum along the labial border and compares more nearly with that development in *Cryptotis parva* (Say), though P_4 is distinct from the P_4 of *C. parva* in general shape. The tooth is robust and the transverse width is but slightly narrower than the anteroposterior diameter. There is no evidence of a

small cusp or slight projection on the anterior face in the region of the cingulum. M_1 and M_2 have a slightly increased transverse diameter in proportion to their anteroposterior diameter when compared with recent *Sorex* of comparable size. Mental foramen below posterior base of the trigonid of M_1. The ramus is not deepened under M_1. Alveoli of P_3 and incisor present. The alveolus of the incisor extends slightly past the midline through P_4. Anteroposterior diameter of P_4-M_2 is 3.15 mm.

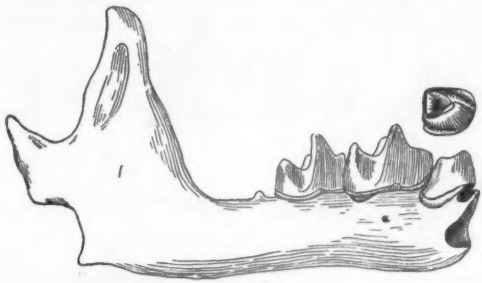

FIGURE 4.—*Ramus of* Sorex cudahyensis *n. sp.*
Holotype, KUMVP 6513. Right ramus, lateral view. ×10

DISCUSSION: I am unable to assign *Sorex cudahyensis* to any known group. It is larger than *Sorex cinereus* and *Sorex taylori* Hibbard. P_4 of *Sorex taylori* from the upper Pliocene is robust though not as large, and it possesses a well-developed anterior cusp which gives it an increased anteroposterior diameter. The cingulum is well developed but is a narrow band, and not broad as in *S. cudahyensis*.

Neosorex lacustris n. sp.

(Fig. 5)

HOLOTYPE: No. 6630, Kansas University Museum of Vertebrate Paleontology, incomplete right ramus bearing M_1-M_3. Paratypes; No. 6624, a fragmentary left ramus bearing M_2, from type locality; Nos. 6622, 6622a, and 6622b from Locality No. 17, three left rami without teeth; and No. 6514, an incomplete right ramus bearing M_2-M_3.

HORIZON AND TYPE LOCALITY: Pleistocene, Meade formation, Meade County, Kansas, Locality No. 10, Cudahy fauna.

DIAGNOSIS: A shrew the size of *Neosorex bendirii albiventer* (Merriam). The characters of the teeth and ramus are those of the genus *Neosorex*. The greatest transverse diameter of M_1, M_2, and M_3 is considerably less in proportion to the anteroposterior diameter of the molars than in the recent forms of *Neosorex*.

DESCRIPTION OF TYPE: Mental foramen large and under anterior root of M_1. Talonid of M_3 well developed, angular, the ridge from the entoconid (Jackson, 1928, p. 15) joins the trigonid midway between the metaconid and protoconid. Trigonid of M_2 and M_3 with acute crest, not obtuse. Talonid of M_2 joins the wall of the trigonid at a more inward position than in *Blarina*, *Sorex*, and recent specimens of *Neosorex*. Cingulum more strongly developed on outer and anterior face of trigonid of M_2 and M_3 than in Recent forms of *Neosorex*. M_3 similar to that tooth in recent forms, but possessing a shorter transverse diameter. Anteroposterior diameter of M_1-M_3 is 4.12 mm.

DISCUSSION: The ramus and M_2 of the paratype No. 6624 and specimen No. 6514 possess the same characters as the type. The anteroposterior diameter of M_2-M_3 of No. 6514 is 2.85 mm. A nearly complete angle is present in paratype No. 6622. The inferior notch (condylo-angular, subcondylar notch of authors) appears square as in *Neosorex b. albiventer* and *Sorex t. trowbridgii* Baird, not rounded as in other *Sorex* and *Blarina* examined. The sigmoid notch (superior, mandibular, condylo-coronoid or supracondylar notch of authors) forms approximately a 45-degree angle. The

pterygoid fossa (intertemporal fossa of authors) well developed, no foramen below ventral border opening into the fossa as generally occurs in *Blarina*. Mandibular foramen (inferior dental, or dental foramen of authors) normal. In *Blarina* the mandibular foramen is well developed and is situated below and anterior to the larger foramen, which when present opens into the pterygoid fossa. In one specimen of *Sorex t. trowbridgii* one large opening provides the common opening for both a

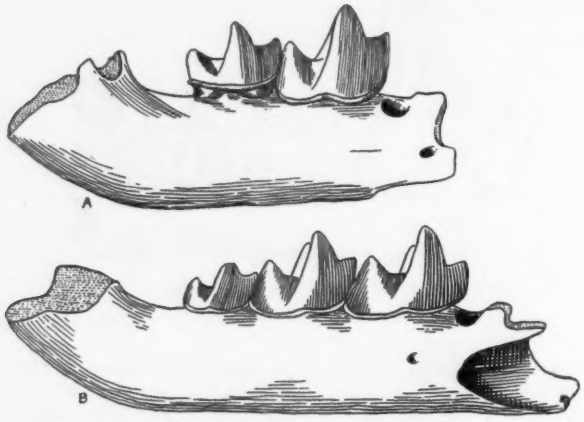

FIGURE 5.—*Rami of* Neosorex lacustris *n. sp.*

(A) Paratype, KUMVP 6514. Right ramus, lateral view. (B) Holotype, KUMVP 6630. Right ramus, lateral view. ×10

large foramen opening into the pterygoid fossa and the mandibular foramen. This is the only specimen of *Sorex* observed to possess a foramen posterior to the mandibular foramen that opens into the pterygoid fossa, a condition observed to be common in *Blarina*. More complete material is needed before one can determine with certainty whether the fossil form belongs to the *palustris* group or the *bendirii* group.

Microsorex pratensis n. sp.

(Fig. 6A)

HOLOTYPE: No. 6470, Kansas University Museum of Vertebrate Paleontology, part of left ramus bearing P_4-M_3. Collected summer of 1941 by Claude W. Hibbard and party.

HORIZON AND TYPE LOCALITY: Pleistocene, Meade formation, Meade County, Kansas, Locality No. 17, Cudahy fauna.

DIAGNOSIS: A shrew larger than *Microsorex hoyi intervectus* Jackson and with a larger P_4, heavier ramus and dentition.

DESCRIPTION OF HOLOTYPE: Fragmentary left ramus of an adult specimen with alveoli of incisor and P_3; bearing P_4-M_3. The shape of P_4 is identical with that of *Microsorex* which separates it from *Sorex*. *Sorex merriami* Dobson is the only form that has a P_4 similar to the P_4 of *Microsorex*, though the P_4 is distinct. P_3 appears to have been smaller than the P_3 in recent *Microsorex* as shown by reduced distance between the alveoli of P_3 and I_2. The mental foramen is situated in relation to M_1 as in *Microsorex hoyi*. The ramus, cingulum and teeth are heavier than in the recent species, though the pattern of the teeth and proportions are identical. Anteroposterior diameter of P_4-M_3 is 3.7 mm. *Microsorex pratensis* is distinguished from *Microsorex minutus* Brown by the normal relation of I_1 to P_4, which is the same as in recent species.

Order CARNIVORA

Family MUSTELIDAE

Mustela sp.

(Fig. 6B)

In the collection from Locality No. 17, Meade County, is a right DP_4 of a small weasel. The tooth is smaller than the milk dentition of *Mustela frenata* Lichtenstein with which it has been compared. The tooth has an anteroposterior diameter of 2.6 mm.; which is approximately the size of DP_4 of *Mustela cicognanii* Bonaparte.

FIGURE 6.—*Ramus of* Microsorex pratensis *n. sp. and tooth of* Mustela

(A) *Microsorex pratensis* n. sp. Holotype, KUMVP 6470. Left ramus, lateral, and occlusal views. ×10. (B) *Mustela* sp. KUMVP 6702, RDP_4. Lateral view. ×10.

This is the only evidence of any carnivore found in these deposits.

Order RODENTIA

Family SCIURIDAE

A number of isolated squirrel teeth were collected at Locality No. 17. The teeth are from at least three distinct groups of squirrels. The largest teeth are as large as those of the prairie-dog, *Cynomys ludovicianus* (Ord), but are distinct from them. The intermediate size compares with *Citellus franklinii* (Sabine) and the smallest with *Citellus tridecemlineatus* (Mitchill). A few isolated teeth were found at Locality No. 10.

Family GEOMYIDAE

(Fig. 7A–D)

A number of isolated gopher teeth were found at Locality Nos. 10 and 17. From a study of the fourth lower premolars, it is evident that two distinct forms of gophers were present, *Parageomys* n. gen. (*See* Tobin fauna for description of genus and species.) The only tooth recovered with the Cudahy fauna was a right P_4, No. 6696, Fig. 16A. The other molars are those of a small form of *Geomys*, Fig. 7A-D.

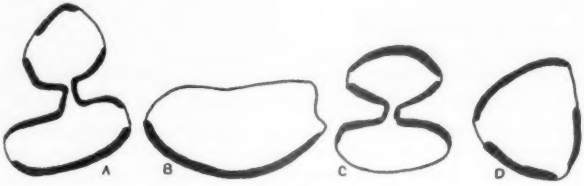

FIGURE 7.—*Teeth of* Geomys *sp.*

Geomys sp. (A) KUMVP 6697, RP^4. (B) KUMVP 6698, RM_1. (C) KUMVP 6699, LP_4. (D) KUMVP 6700, LM^2. Occlusal views. ×10.

Family CRICETIDAE

Reithrodontomys cf. *pratincola* Hibbard

Reithrodontomys pratincola HIBBARD, 1941, Kansas Geol. Survey, Bull. 38, pt. 7, p. 209–210.

A fragmentary left maxillary, No. 6615, containing an adult M^1 was recovered in Meade County, Kansas, at Locality No. 17. The specimen is too fragmentary for identification but compares with the maxillary (Hibbard, 1942, p. 266) recovered from the Borchers fauna, Meade County, which was taken from the Meade formation above the Pearlette ash.

Peromyscus cragini n. sp.

(Fig. 8)

HOLOTYPE: No. 6618, Kansas University Museum of Vertebrate Paleontology, part of left ramus bearing incisor, M_1-M_3. Referred material: fragmentary left maxillary, No. 6616, bearing M^1; and No. 6619, a fragmentary right ramus bearing M_2. Collected summer of 1942 by Claude W. Hibbard and party.

HORIZON AND TYPE LOCALITY: Pleistocene, Meade formation, Meade County, Kansas, Locality No. 17, Cudahy fauna.

DIAGNOSIS: A form slightly smaller than *Peromyscus maniculatus nebrascensis* (Coues) with the valleys between the cusps broader and more open, not as deep. Accessory cusps not well developed, only vestigal if present. M_1 has a narrow transverse diameter in comparison to its length.

DESCRIPTION OF HOLOTYPE: A left ramus of an adult mouse with the coronoid process and angle missing. M_1 smaller than M_1 of *P. m. nebrascensis* with no evidence of accessory cusps, except a small protoconulid (Goldman, 1918, p. 11) which is distinct from the paraconid. The tooth is narrower and the valleys between the cusps as broad but not sloping as in *Onychomys*. The cusps are not as strongly developed as in *P. m. nebrascensis*. The cingulum is developed as a thin band connecting the protoconid and hypoconid but is not thickened as it would be in the development of a small cusplet. Metaconid of M_2 well developed, only a slight indication of a protoconulid exists. In teeth of comparable stage of wear of *P. m. nebrascensis* there exists a narrow deep valley between the protoconulid and protoconid which does not exist in the fossil form. M_3 is distinct in that a broad rounded valley separates the protoconid and hypoconid. At the base of the valleys in both M_2 and M_3 there is a thin band of enamel between the protoconid and hypoconid with indication of the development of an accessory cusp. This slight thickening may be a forerunner of the well-developed cusplets. The mental and mandibular foramina are developed and situated as in *P. m. nebrascensis*. This species is named for Dr. F. W. Cragin, who collected the first vertebrate fossils from this area.

DISCUSSION: The M_2 in the immature ramus is unworn and compares perfectly in development with that tooth in a ramus of an immature *P. e. eremicus* (Baird) in which M_3 has not erupted.

On the referred M^1 there are no accessory cusps, the valleys between the cusps are broader than in *P. m. nebrascensis*.

Peromyscus cragini is distinct from *Peromyscus kansasensis* Hibbard, from the Rexroad fauna of Meade County, because of its smaller size, narrower molars, and the presence of the enamel cingulum that joins the base of the cusps mentioned. The valleys between the cusps in *P. kansasensis* are completely open at the base. *Peromyscus eliasi* Hibbard from the Rexroad fauna is not a *Peromyscus* but is synonymous with *Bensonomys arizonae* (Gidley). The anteroposterior diameter of M_1-M_3 of the type of *Peromyscus cragini* is 3.5 mm.; of *P. kansasensis*, 4.1 mm.; of *P. m. nebrascensis*, 3.55 mm.

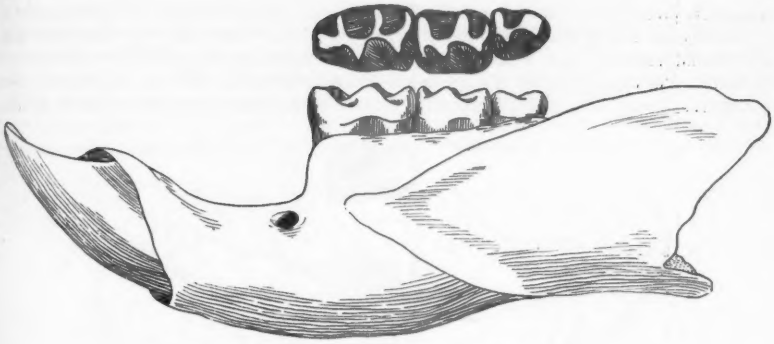

FIGURE 8.—*Ramus of* Peromyscus cragini *n. sp.*
Holotype, KUMVP 6618. Left ramus, lateral and occlusal views. ×10

Cudahyomys n. gen.

GENOTYPE: *Cudahyomys moorei* n. sp., No. 6690, Kansas University Museum of Vertebrate Paleontology; incomplete left ramus bearing incisor and M_1. Collected summer of 1941 by Claude W. Hibbard and party.

DIAGNOSIS: A mouse intermediate in size between *Reithrodontomys megalotis* (Baird) and *Peromyscus maniculatus* (Wagner); M_1 broad in comparison with anteroposterior length. Metaconid (Goldman, 1918, p. 11) continuous with the paraconid and protoconulid. No valley separating the cusps. Protoconulid continuous with protoconid, only a very shallow pit between the cusps. No groove on face of anterior lobe. The tooth is that of a young adult animal.

Cudahyomys moorei n. sp.

(Fig. 9)

HOLOTYPE: No. 6690, Kansas University Museum of Vertebrate Paleontology, incomplete ramus bearing incisor and M_1. Collected summer of 1941 by Claude W. Hibbard and party.

HORIZON AND TYPE LOCALITY: Pleistocene, Meade formation, Meade County, Kansas. Locality No. 17, Cudahy fauna.

DESCRIPTION OF HOLOTYPE: An incomplete left ramus. Anteroposterior diameter of M_1 is 1.15 mm.; greatest transverse diameter is 0.8 mm. Alveolar length of M_1-M_3 is 2.7 mm. The paraconid is completely lacking or greatly reduced and completely fused with the protoconulid. The anterior region of M_1 is reduced so that a slight groove occurs where a valley should exist between the paraconid and the metaconid. The groove is along the lingual side of the tooth, does not extend to the base and would soon disappear with wear. In fact, due to the anteroposterior shortening of the tooth this groove is situated approximately where the paraconid should be in relation to the protoconulid. This condition is produced in part by the broadly developed valley or internal re-entrant angle between the metaconid and entoconid. This valley is as broad as in *Peromyscus maniculatus* and possesses no accessory cusp. The entoconid is narrow and a deep narrow valley separates it from the hypoconid. There is no evidence of an entostylid. The protoconulid is well developed and extends posteriorly as a narrow ridge (that is, a continuation of the outer wall of the tooth) to the posterior part of the protoconid. Therefore no external re-entrant angle or valley exists between the protoconulid and the protoconid. A pit does exist between the protoconid and the backward extension of the protoconulid in the region where a valley should occur. A broad deep valley occurs

between the protoconid and the hypoconid. The hypoconid is shifted lingually, lies chiefly posterior to the entoconid and produces the posterior face of the tooth. With slight wear the protoconid, protoconulid, paraconid, and metaconid would form one continuous unity or the anterior part of the tooth. The mental foramen is larger and is situated a little more dorsally and lingually than in *Reithrodontomys*. The capsular process for the base of the incisor is similar to that in *Reithrodontomys* as well as the development of the mandibular foramen and its relation to the coronoid process.

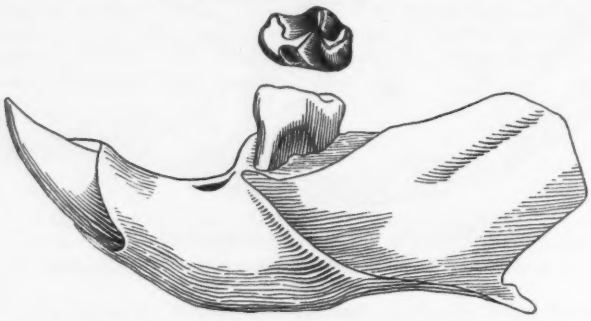

FIGURE 9.—*Ramus of* Cudahyomys moorei *n. gen., n. sp.*
Holotype, KUMVP 6690. Left ramus, lateral and occlusal views. ×10

I know of no form from the Pliocene or Pleistocene to which *Cudahyomys* is closely related. The tooth pattern is distinct. The characters of the ramus show a closer relationship to *Reithrodontomys* than to any of the other known fossil Cricetines from the Pliocene or Pleistocene. This species is named for Dr. Raymond C. Moore.

Synaptomys (*Mictomys*) *borealis* (Richardson)
(Fig. 10B–F)

Arvicola borealis RICHARDSON, 1828, Zool. Jour., vol. 3, p. 517.

Five rami bearing teeth, and a number of isolated teeth were recovered that are not separable from *Synaptomys borealis*. The fragmentary jaws vary in size; this appears to be an age character. Three fragmentary rami were taken at Locality No. 17, Meade County. Specimen No. 6610 is a left ramus bearing M_1-M_2 with an anteroposterior diameter of 4.35 mm. No. 6188 is a right ramus bearing M_1-M_2 having an anteroposterior diameter of 5.2 mm.

DESCRIPTION OF SPECIMEN: No. 6189 is a fragmentary left ramus bearing M_1-M_2. The mental foramen and masseteric ridge are the same as in *Synaptomys borealis*. M_1 consists of a posterior loop and two tightly closed triangles and an anterior loop. Third triangle larger than in the recent species with broader base on labial side. The anterior loop is larger and more triangular in shape than that of *S. borealis*. M_2 consists of three closed triangles. The third or anterior triangle is set off from the second more distinctly than that in the recent species. It is more nearly the shape of an equilateral triangle. Anteroposterior diameter of M_1-M_2 is 4.8 mm.

A fragmentary left ramus, No. 6658, bearing M_1 was taken at Locality No. 20, Meade County. The anteroposterior diameter of the tooth is 2.8 mm.

A right ramus, No. 6625, bearing M_1-M_2 was taken from Locality No. 10, Meade County. The anteroposterior diameter is 4.3 mm.

Teeth of *Synaptomys borealis* were taken in the NW¼, sec. 33, T. 31 S., R. 28 W. from the silt below the volcanic ash in Meade County.

Synaptomys borealis comes from a lower horizon in the Meade formation of Meade County than the Borchers fauna, from which *Synaptomys* cf. *vetus* Wilson was reported.

Synaptomys cf. *vetus* Wilson, specimen No. 6151 from the Borchers fauna, was incorrectly referred by Hibbard (1941) to the subgenus *Mictomys*; also *Synaptomys vetus* Wilson and *S. annexus* Peterson by Hibbard in 1940. The subgenus *Synaptomys* at present must be considered to include such forms as *S. vetus* which possess open external triangles present in M_1 and M_2. There is no indication of an open external triangle in M_1 or M_2 in the subgenus *Mictomys*. The recent forms of the subgenus *Synaptomys* may have been derived from a form such as *S. vetus*, but it seems that

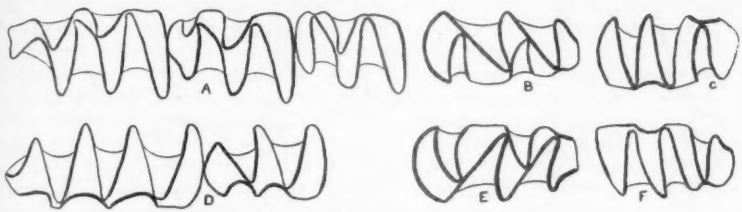

FIGURE 10.—*Dentition patterns of* Synaptomys

(A) *Synaptomys cooperi annexus* (Peterson). CM 11271. (B) *Synaptomys borealis*. KUMVP 6625b, LM^1. (C) *Synaptomys borealis*. KUMVP 6684, LM^2. (D) *Synaptomys borealis*. KUMVP 6189, LM_1-M_2. (E) *Synaptomys borealis*. KUMVP 6625a, RM^1. (F) *Synaptomys borealis*. KUMVP 6682, RM^2. Occlusal views. All ×10.

vetus appeared too late to be ancestral. The specimen from the Borchers fauna can not be considered as intermediate between the subgenera *Mictomys* and *Synaptomys*, since all characters present are distinctly those of the subgenus *Synaptomys*.

Mr. Kay of the Carnegie Museum has kindly loaned me the two paratypes of *Synaptomys cooperi annexus* from the Frankstown Cave fauna of Pennsylvania for study. I can not believe that Peterson's type differs as much from the paratypes as is shown by Peterson (1926, Figure 4). Apparently what Peterson called the external anterior angle of M_1 is the anterior loop. In paratype No. 11271 C.M. (Fig. 10A) the anterior loop is slightly larger than the anterior loop in specimens of *Synaptomys cooperi cooperi* Baird with which comparisons were made. The anterior re-entrant angles, both internal and external, are present on the loop and are not as concave as in the recent form, but are nearly straight producing a better-developed anterior loop. M_1 in the paratype consists of a posterior loop, three alternating closed triangles and an anterior loop. The second closed triangle of M_1 is not as tightly closed where it joins the anterior loop as it is in the recent specimens examined, though the closed triangles of M_1 in paratype No. 11272, Carnegie Museum, are as tightly closed as in the recent specimens. The paratypes do not possess the deeper and narrower external re-entrant angles assigned to the type by Peterson when compared with the recent specimens at hand. The incisor of specimen No. 11272 C.M. ends opposite the posterior border of the anterior loop of M_3. It has been broken away on the other paratype.

The greatest difference observed between *S. c. annexus* and *S. c. cooperi* is that the mental foramen is slightly farther in front of M_1 in the fossil forms than in the recent specimens. The mental foramen of specimen No. 11272 approaches more nearly the condition as it exists in the recent specimens examined, while in specimen No. 11271 the mental foramen is still farther forward. The type of *S. c. annexus* should be carefully checked with the paratypes and other specimens of *S. c. cooperi*. Wilson (1933) is correct in his comparison of *annexus* with *vetus* based upon Peterson's figure, but if the paratypes are the same as the type, Peterson's figure is incorrect and *annexus* belongs definitely to *S. cooperi*. The anteroposterior diameter of M_1-M_3 of No. 11271 C.M. taken at occlusal surface is 6.0 mm.; of No. 11272 C.M. is 5.6 mm.

Microtus paroperarius n. sp.

(Fig. 11)

HOLOTYPE: No. 6587, Kansas University Museum of Vertebrate Paleontology, part of right ramus; bearing M_1 and M_2. Paratypes from the type locality, Nos. 6584, right ramus bearing M_1-M_2s

6585, right ramus bearing M_1-M_2; 6588, left ramus bearing M_1-M_2; 6590, right ramus bearing M_1-M_2; 6591, right ramus bearing M_1-M_2; 6594, left ramus bearing M_1; 6596, right ramus bearing M_1-M_2; 6600, left ramus bearing M_1; 6601, right ramus bearing M_1-M_2; 6602, right ramus bearing M_1-M_2; 6603, left ramus bearing M_1; 6604, right ramus bearing M_1; 6605, left ramus bearing M_1-M_2; 6607, left ramus bearing M_1. Paratypes from Locality No. 10, Meade County, Kansas: Nos. 6627, left

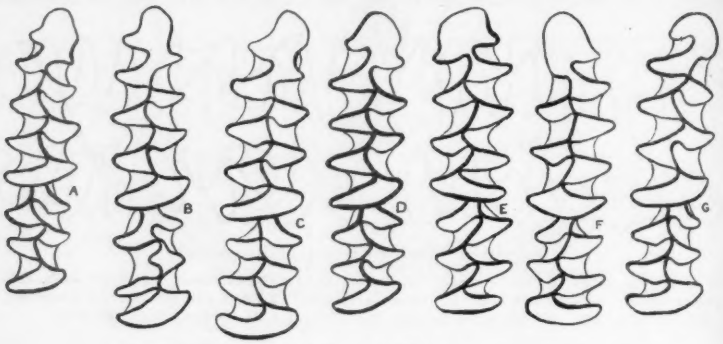

FIGURE 11.—*Dentition patterns of* Microtus paroperarius *n. sp.*

(A) Holotype, KUMVP 6587, RM_1-M_2. (B) Paratypes, KUMVP 6590, RM_1-M_2. (C) KUMVP 6584, RM_1-M_2. (D) KUMVP 6628, RM_1-M_2. (E) KUMVP 6627, LM_1-M_2. (F) KUMVP 6588, LM_1-M_2. (G) KUMVP 6596, RM_1-M_2. Occlusal views. All ×10.

ramus bearing M_1; 6628, right ramus bearing M_1; 6629, left ramus bearing M_1-M_2; 6639, left ramus bearing M_1. Collected summers of 1941 and 1942 by Claude W. Hibbard and party.

HORIZON AND TYPE LOCALITY: Pleistocene, Meade formation, Meade County, Kansas, Locality No. 17, Cudahy fauna.

DIAGNOSIS: A small vole the size of *Microtus sitkensis* Merriam, belonging to the *M. operarius* group. M_1 consists of a posterior loop, four tightly closed triangles, the fifth opening into the anterior loop which bears evidence of the fifth internal and fourth external re-entrant angles, the anterior loop not rounded or crescent-shaped as in recent forms of the *operarius* group.

DESCRIPTION OF HOLOTYPE: Fragmentary left ramus bearing M_1 and M_2. Mental foramen as in *Microtus operarius* (Nelson). Pit deeper between M_3 and ascending ramus than in *M. operarius* and not as shallow as in *M. sitkensis*. M_1 consists of a posterior loop, six alternating triangles and an anterior loop. The first four triangles are tightly closed. The fifth opens widely into the anterior loop with which the sixth is confluent. There are four external re-entrant angles. The apex of the third is broader than the first or second. The fourth re-entrant angle is shallow. There are four well-developed inner re-entrant angles and the fifth is shallow. M_2 consists of a posterior loop and four alternating closed triangles; the fourth is more rectangular than triangular in outline (Fig. 11A). The teeth are completely rootless, possessing an open base. Cement present in re-entrant angles. The incisor passes from the lingual to the labial side between M_2 and M_3. Anteroposterior diameter of M_1-M_2 is 4.4 mm. Comparing the paratypes with the type, 22 have the same M_1 patterns, though they differ slightly in stage of wear of the dentition. Specimen No. 6627, Locality No. 10, which was taken 11 miles due north of Locality No. 17, from the same horizon below the volcanic ash has an anterior loop that is rounded (Fig. 11E). Paratypes Nos. 6588 and 6596 have an M_1 with a crescentic anterior loop as in *Microtus operarius* (Fig. 11F, G). The anteroposterior diameter of M_1-M_2 of these specimens is slightly larger than the type, being respectively 4.7 and 4.5 mm.

Isolated first lower molars of *Microtus paroperarius* have also been recovered from the following localities in Meade County, Kansas, from the silt deposit directly below the volcanic ash; $SE\frac{1}{4}$ $NE\frac{1}{4}$ sec. 4, T. 32 S., R. 28 W., and from the $NW\frac{1}{4}$ sec. 13, T. 31 S., R. 28 W.

DISCUSSION: It is impossible to compare the size of this species with the fossil forms *Microtus arvalinus* Hinton, *M. nivaloides* Forsyth Major, *M. nivalinus* Hinton, and *M. ratticepoides* Hinton, from the upper Freshwater Bed at West Runton, Norfolk, England, since measurements are not given.

I have either confused a number of races of *M. paroperarius* or there is considerable variation in the anterior loop due to age and wear; the latter is my interpretation. Hinton has what appears to be teeth of *M. ratticepoides* confused with *M. arvalinus* and *M. nivalinus*. Hinton's subfigures 9 and 11 of Fig. 65, (1926, p. 128) of *M. arvalinus* show an M_1 with four tightly closed triangles with the fifth opening confluently into the anterior loop. This is also the case in subfigure 28 of *M. nivalinus*; subfigure 23 of *M. nivaloides* may be questioned. From a study of the recent groups of *Microtus* in North America the presence of four closed triangles following the posterior loop with the fifth triangle opening into the anterior loop appears to be a constant group character.

In case a number of races have been confused they all belong to a closely related group and their presence together probably is due only to crowding caused by the climatic change.

I consider *Microtus paroperarius* closely related to Cope's *Microtus speothen* from the Port Kennedy bone deposit. I was unable to examine Cope's types. From a study of his type description and figure, *M. speothen* is characterized by possessing an M_1 with a posterior loop, four alternating closed triangles with the fifth triangle confluent with the anterior loop. There seems to be a slight error in Cope's drawing of the anterior loop of this tooth. A careful study should be made of Cope's forms when the types are available. *Microtus paroperarius* is distinguished from *M. speothen* by its smaller size. Cope's (1871, p. 91) figure of *Microtus involutus* differs considerably from his description in that the figure of M_1 consists of a posterior loop, four alternating closed triangles and a crescentic anterior loop, which compares well with our specimen No. 6596 (Fig. 11G). Cope (1899, p. 208) in his discussion states in regard to M_1

"The trefoil is of peculiar shape, which distinguishes the molar from the corresponding one of *M. didelta* to which this species is nearly allied. The two basal, open triangles are present, and anterior to these are two angles which are not opposite, and one of which is much more prominent than the other. Anterior to these there is no lobe such as is characteristic of the species of *Microtus* generally, but the anterior border passes from one angle to the other. As one angle is much more prominent than the other, and is more anterior, the resulting figure is a hook, of which the more prominent angle is the point."

Cope considered the triangle formula of the M_1 as consisting of a posterior loop, three alternating triangles and an anterior loop. As stated before, the drawing shows four alternating closed triangles. In the discussion the anterior loop is spoken of as trefoil or reference to a loop of three parts, that is, two broadly confluent triangles opening widely into the anterior loop. In the description he considers the anterior loop itself as missing and in its place two angles which are not opposite and the resulting figure is a hook. He speaks of two basal open triangles posterior to the hook. These would be his second and third alternating triangles. This condition is not shown in the figure. I am uncertain, but from the description the fourth and fifth triangles are confluent and may open into the anterior loop. For this reason, the type should be checked; if the figure is correct it is either *Microtus speothen* or a closely related form and not related to *Pitymys* as considered by Cope. On the other hand, if the figure is incorrect and the description is correct it is probably an old specimen of *Microtus didelta* Cope which can be referred to either *Pedomys*, *Neodon*, or *Pitymys*, since the skull is not known. Other evidence that his discussion is correct and the figure incorrect is that M_2 consists of a posterior loop, two closed triangles with the third and fourth confluent, a character not found in *M. speothen* but common with *M. didelta*.

Microtus (*Pedomys*) *llanensis* n. sp.

(Fig. 12)

HOLOTYPE: No. 6626, Kansas University Museum of Vertebrate Paleontology, part of left ramus bearing M_1-M_2 of an old adult. Collected summer of 1942 by Claude W. Hibbard and party.

HORIZON AND TYPE LOCALITY: Pleistocene, Meade formation, Meade County, Kansas, Locality No. 10, Cudahy fauna.

DIAGNOSIS: A small vole nearly the size of *Microtus ochrogaster minor* (Merriam). M_1 consists of a posterior loop, three alternating tightly closed triangles, and confluent fourth and fifth triangles that open widely into the anterior loop. M_2 consists of a posterior loop and four alternating triangles. The first and second triangles tightly closed. The third and fourth triangles confluent. The contact between the confluent third and fourth alternating triangles of M_2 with the posterior loop of M_1 is distinct from the contact of M_1 with M_2 in the recent form of *Pedomys* and *Pitymys* in North America. Teeth rootless and re-entrant valleys filled with cement.

FIGURE 12.—*Lower molar pattern of* Microtus (Pedomys) llanensis *n. sp.*

Holotype, KUMVP 6626, left M_1-M_2. Occlusal view. ×10

DESCRIPTION OF HOLOTYPE: Fragmentary right ramus bearing M_1 and M_2. M_1 consists of a posterior loop and three tightly closed alternating triangles. The fourth and fifth triangles confluent and open broadly into a small anterior loop. Four inner and three outer re-entrant angles, no indication of a fourth or fifth re-entrant angle exists. Enamel band much thicker on anterior face of alternating triangles than on the posterior face. M_2 consists of a posterior loop, two closed alternating triangles, third and fourth confluent. M_3 was slightly reduced and offset due to passing of incisor root from lingual to labial side between M_2 and M_3. There is a shallow pit between M_3 and ascending process of the ramus. The pit is much shallower than in *Microtus paroperarius*. Anteroposterior diameter of M_1-M_2 is 4.5 mm.

DISCUSSION: The specimen has been placed in the subgenus *Pedomys* because of two characters, the size and relationship of the basal capsular process for M_3 in relation to the angular process, and the well-developed foramen between the anterior outer triangle of M_2 and the edge of the ascending ramus. These characters seem to correspond more nearly to *Pedomys* than to *Pitymys*, though the pit between M_3 and the ascending ramus is shallower than in any known recent *Pedomys* and in this character more nearly approaches the condition in the recent *Pitymys*, though it is still shallower. Until more is known of the species it can not be assigned to either group with certainty.

A careful examination of the M_1 and M_2 series of *Microtus paroperarius* and especially of old worn teeth in no way indicates that this is an aberrant dentition of that form; if so, the other characters of the ramus are aberrant. No other molars of this form were found.

Cope described two forms from the Port Kennedy Bone Deposit, *Microtus didelta* and *M. involuta* which he considered allied to *Pitymys pinetorum* (LeConte). As stated previously, the dentition pattern of M_1 of *M. involuta* should be restudied. The presence of the confluent alternating third and fourth triangles in M_2 indicate that the M_1 was misfigured.

Microtus didelta appears to be closely related to *Microtus* (*Pedomys*) *llanensis*. Whether Cope's form is more nearly related to *Pitymys* than *Pedomys* will be determined by the recovery of a skull in association with the lower jaw.

Pitymys meadensis n. sp.

(Fig. 13A–F)

HOLOTYPE: No. 6463, Kansas University Museum of Vertebrate Paleontology, incomplete left ramus bearing M_1-M_2. Paratypes from type locality; Nos. 6462, fragmentary right ramus bearing M_1; 6190, fragmentary left ramus bearing M_1; 6586, right ramus bearing M_1-M_2; 6589, right ramus bearing M_1; 6592, left ramus bearing M_1-M_2; 6593, left ramus bearing M_1-M_2; 6595, left ramus bearing M_1-M_2; 6597, right ramus bearing M_1-M_2; 6599, left ramus bearing M_1. Collected summer of 1942 by Claude W. Hibbard and party.

HORIZON AND TYPE LOCALITY: Pleistocene, Meade formation, Meade County, Kansas, Locality No. 17, Cudahy fauna.

DIAGNOSIS: A vole the size of *Microtus nevadensis* Bailey: M_1 with a posterior loop, seven alternating triangles and an anterior loop. Posterior loop, first, second, and third alternating triangles tightly closed; the fourth and fifth triangles confluent, the fifth is closed from the sixth which is confluent with the seventh; the sixth and seventh open widely into the rounded anterior loop, thus becoming a part of the loop. M_2 consists of a posterior loop and four alternating closed triangles. Teeth rootless; re-entrant angles contain cement.

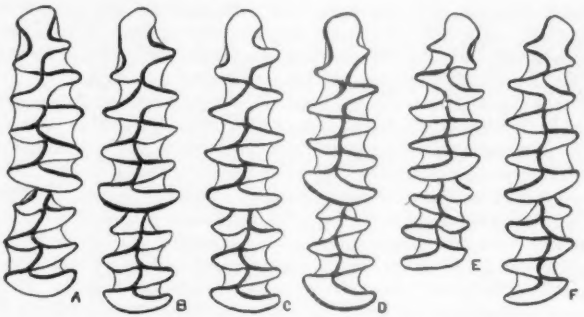

FIGURE 13.—*Dentition patterns of* Pitymys meadensis *n. sp.*

(A) Holotype, KUMVP 6463, LM_1-M_3. (B) Paratype, KUMVP 6592, LM_1-M_3. (C) Paratype, KUMVP 6593, LM_1-M_3. (D) Paratype, KUMVP 6595, LM_1-M_2. (E) Paratype, KUMVP 6586, RM_1-M_2. (F) Paratype, KUMVP 6597, RM_1-M_3. Occlusal views. All ×10.

DESCRIPTION OF TYPE: The ramus is that of an adult, with M_3, condyle, angle, and coronoid process missing. The outer salient angles of M_1 are broad at their apex, the outer triangles are smaller than the inner triangles. The enamel is thickened on the anterior face of the triangles and thinned on the posterior border. The fourth inner re-entrant or salient angle has a broader apex than the other inner angles. The fourth and fifth alternating triangles are strongly confluent and tightly closed off from the anterior loop. The outer salient angles of M_2 are larger than the inner salient angles. The enamel is thicker on the anterior face of the alternating triangles than on the posterior face. The posterior loop is completely closed off from the four closed triangles. There is a well-developed foramen opposite the posterior part of M_2, also a well-developed pit opposite M_3. The re-entrant angles are filled with cement (Fig. 13A). The incisor passes from the lingual to the labial side between M_2 and M_3. Anteroposterior diameter of M_1 is 2.8 mm. Anteroposterior diameter of crown of M_1 and M_2 is 4.4 mm. The tooth pattern of M_1 of the paratypes agrees with that of the type. Anteroposterior diameter of M_1 of No. 6462 is 2.8 mm. Anteroposterior diameter of M_1-M_2 or other paratypes are as follows: Nos. 6586, 4.15 mm.; 6592, 4.6 mm.; 6593, 4.6 mm.; 6595, 4.4 mm.; 6597, 4.35 mm.; 6304, 4.1 mm. The first lower molars of *Pitymys meadensis* were also recovered in Clark County from the silt below the ash on the Pyle Ranch in sec. 11, T. 30 S., R. 23 W.; and from Meade County, Kansas, in sec. 4, T. 32 S., R. 28 W. and sec. 2, T. 31 S., R. 28 W. from the silt below the ash.

DISCUSSION: The pattern of M_1 of *Pitymys meadensis* compares well with that of *Pitymys arvaloides* Hinton (1926, No. 1, Fig. 64, p. 127) from the Upper Freshwater Bed at West Runton. The pattern of M_2 of our species differs from this specimen figured by Hinton in that the third and fourth triangles are closed and not confluent. This closure of the triangles occurs in the other four specimens figured by Hinton. A comparison as to size of the Meade County specimens with *Pitymys arvaloides* and *Pitymys gregaloides* Hinton is impossible since Hinton (1923) does not give any measurements and only states that they are smaller than the living forms with which they are compared. An examination of 95 lower jaws of our Recent *Pitymys nemoralis* (Bailey) does not show any of the Recent specimens with triangles three and four closed in M_2. In fact the third and fourth triangles are

broadly confluent, with the exception of two specimens. In one there is a tendency for a constriction between these two triangles while in the other specimen these triangles are half closed due to the increased depth of the second outer re-entrant angle. The pattern of M_1 of recent specimens of *Pitymys* is usually figured showing the confluent triangles four and five as opening rather broadly into the anterior loop. In the 95 specimens of the Recent species *Pitymys nemoralis*, 42 specimens have an M_1 in which the fourth and fifth confluent triangles are closed off from the anterior loop. Many are as tightly closed as in the fossil form. This condition is not due to age in the recent specimens but is a variable character. Only one of the fossil specimens shows any tendency to vary in this character, No. 6586, an old adult, in that the enamel of the re-entrant angles is not so closely appressed as in the others. It can not be considered as open since the dentine of the anterior loop and the dentine of the confluent fourth and fifth triangles are not connected.

The patterns of M_1 and M_2 of *Pitymys meadensis*, *P. arvaloides*, and *P. gregaloides* seem more closely related to the living genus *Neodon* of southeastern central Asia than to our living forms of *Pitymys*. Complete skulls of these forms are needed to determine their true relationship. It seems that these fossil forms were generalized, and without doubt terrestrial in habit. They appear to represent the line of ancestral stock from which *Pitymys*, *Neodon*, *Phaiomys*, *Pedomys*, and possibly *Herpetomys* and *Tyrrhenicola* could be derived. *Pitymys meadensis* appeared too late to be ancestral, for associated with it is a more advanced form in which the fourth and fifth confluent triangles open widely into the anterior loop and the third and fourth triangles of M_2 are broadly confluent. Hinton figured an M_2 of *Pitymys arvaloides* with confluent third and fourth triangles. Here the tendency for this variation appears early. Associated with the fossil *Pitymys* from the Upper Freshwater Bed at West Runton, Norfolk, England, Hinton (1923) described four species of *Microtus*, which substantiates the evidence that the *Microtus* and *Pitymys* lines of development separate at an early date. External characters have greatly influenced the determination of the relationship of the groups and subgenera of *Microtus*. Hinton was apparently the first to appreciate the true relationship as shown by the development of the tooth pattern. If *Pitymys* is considered to be of more than subgeneric rank it necessitates a critical study of the entire genus of *Microtus* and the removal from that genus of a number of forms that at one time or another have been considered as genera or subgenera, and placing them under the genus *Pitymys*, regardless of external characters, if true relationships are to be shown.

The present distribution of *Pitymys* is confined to the mild temperate region of North America and Europe.

Hinton (1926, p. 56) accounts for the present fossorial habits of *Pitymys* as follows: "In face of the severe competition offered to it in Europe and N. America by the very numerous species of *Microtus*, *Pitymys* has been forced to adopt fossorial habits."

Another explanation may possibly account for the present fossorial habits of *Pitymys*. It may have been crowded southward by the ice into a region which normally was much warmer than that originally occupied by it. Our voles as a rule are semifossorial forms, that is, living in burrows, in part. A form subjected to increased temperature would find an escape in confining itself chiefly to its burrows. A form so confined would easily become stranded by the retreat of the ice, and to maintain itself must therefore have adapted itself to a fossorial habit. An increase in aridity would further restrict a form adapted chiefly to a fossorial habit. The population would be thus confined to areas supporting tall vegetation which would shade the ground and help retain the moisture. It is in this type of environment that *Pitymys* is now found living in North America, chiefly along the edge of forested areas and wooded or brushy fence rows. In this habitat, it is not a direct competitor of *Microtus* which occurs in the same region. *Microtus* itself is confined to the area densely covered with tall grass.

Ondatra kansasensis n. sp.

(Fig. 14A-L)

HOLOTYPE: No. 6656, Kansas University Museum of Vertebrate Paleontology, left M_1 of an adult muskrat. Collected summer of 1942 by Claude W. Hibbard and party.

HORIZON AND TYPE LOCALITY: Pleistocene, Meade formation, Meade County, Kansas, NE¼, sec. 13, T. 31 S., R. 28 W., Locality No. 20, Cudahy fauna.

DIAGNOSIS: A muskrat slightly smaller than *Ondatra annectens* (Brown), having a typical *Ondatra* tooth pattern. Re-entrant angles of anterior loop no deeper than in living species. Alternating triangles in adult closed.

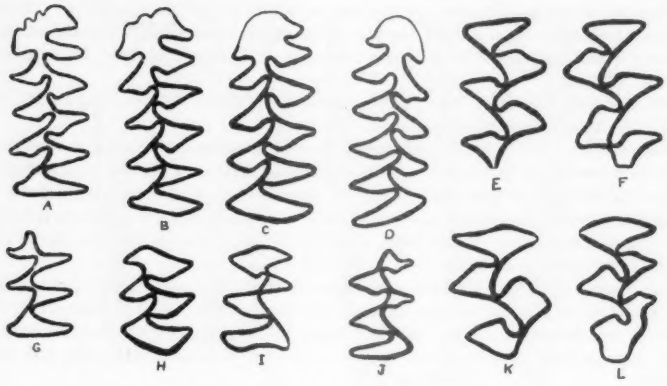

FIGURE 14.—*Teeth of* Ondatra kansasensis *n. sp.*

(A) Paratype, KUMVP 6669, LM_1. (B) Paratype, KUMVP 6668, LM_1. (C) Holotype, KUMVP 6665, LM_1. (D) Paratype, KUMVP 6667, RM_1. (E) Paratype, KUMVP 6671, RM^1. (F) Paratype, KUMVP 6670, LM^1. (G) Paratype, KUMVP 6661, LM_2. (H) Paratype, KUMVP 6657, LM_2. (I) Paratype, KUMVP 6666, RM_2. (J) Paratype, KUMVP 6464, RM_2. (K) Paratype, KUMVP 6660, RM^2. (L) Paratype, KUMVP 6664, LM^2. Occlusal views. ×6.

DESCRIPTION OF TYPE: Left M_1 of an adult specimen. M_1 consists of a posterior loop, seven alternating triangles and an anterior loop. The first five alternating triangles are closed and the dentine of one triangle is not continuous with that of the other since the enamel of the re-entrant angles touch. The sixth and seventh triangles open into the anterior loop. There are four outer and five inner re-entrant angles. The inner triangles are the largest. The apex of the fourth inner re-entrant angle is opposite the apex of the fourth outer re-entrant angle. The opening of the sixth alternating triangle into the anterior loop is half the size of the opening of the seventh alternating triangle (Fig. 14C). The tooth has two well-developed roots. The posterior root is smaller and supports the posterior loop and the first and second alternating triangles. The larger anterior root supports the rest of the tooth. No cement is present in the re-entrant angles of the type or paratypes. The tooth has an anteroposterior diameter of 5.4 mm.

A RM_2, No. 6657 (Fig. 14H), was recovered from the type locality with an anteroposterior diameter of 2.85 mm. It has two roots. The posterior root is the larger and supports the posterior loop and the first alternating triangle.

At Locality No. 10 three lower first molars were taken along with other isolated teeth. Specimen No. 6669, a left M_1 (Fig. 14A), is less worn than the type, and the roots are not closed at the base. The anterior loop of this tooth is complicated in that four shallow re-entrant folds are found on the anterior face of the tooth in the enamel. The first alternating triangle is closed off completely from the posterior loop, but the enamel of the other re-entrant angles does not meet as in the type and the dentine is continuous from the first alternating triangle to the anterior loop, a character common to *O. oregonus* Hollister and *O. annectens*. The re-entrant angles of the anterior loop are normal and are no deeper than in recent forms. The anteroposterior diameter of the tooth is 5.0 mm.

In the other immature specimen, a LM_1, No. 6668 (Fig. 14B), only two of the anterior re-entrant folds are present on the anterior loop, and these are very shallow and would soon disappear with wear. The enamel folds of the re-entrant angles meet so that the first five alternating triangles are closed

though the enamel is not as appressed as in the type, an older specimen. The anteroposterior diameter of the tooth is 5.2 mm.

Specimen No. 6666, a RM_1, is from an adult with an anteroposterior diameter of 5.2 mm. Its dental pattern is the same as the type, except that the crown is worn down so that the opening of the sixth alternating triangle into the anterior loop is much wider than in the type.

A number of molars were recovered from the same horizon at Locality No. 17. A RM_1, No. 6662, is from an old adult. The crown is only half the height of the other specimens. The first four alternating triangles are tightly closed, the fifth opens jointly with the sixth into the anterior loop. The tooth is wider than the others and has a transverse diameter of 2.45 mm. Its anteroposterior diameter is 5.75 mm.

A RM^2, No. 6660 (Fig. 14K), has an anteroposterior diameter of 3.2 mm.; and a LM^2, No. 6664 (Fig. 14L), has an anteroposterior diameter of 3.15 mm.

DISCUSSION: Since only isolated teeth were recovered it is impossible to know whether the inferior notch is rounded as in the recent *Ondatra zibethicus* (Linnaeus) which occurs in that region. I have separated it from *Ondatra oregonus* and *O. annectens* on the normal pattern of the anterior loop. It approaches *O. annectens* in size but appears to be smaller since *O. annectens* is known only from an immature specimen. Brown (1908, p. 197) gives the anteroposterior diameter of M_1 as 3.7 mm. which is corrected by Hollister (1911, p. 33) to 5.7 mm.

In comparison of the RM_2 of *Ondatra kansasensis* with the RM_2 of the *Ondatra* taken from Locality No. 9, Meade County, Kansas, in association with the Borchers fauna which occurs at the top of the ash in the Meade formation, we find that the tooth of the muskrat from the Borchers fauna is considerably larger, with an anteroposterior diameter of 3.65 mm. in comparison with 2.65 mm. in *O. kansasensis*.

Order PERISSODACTYLA

Family EQUIDAE

Equus cf. *niobrarensis* Hay

(Fig. 15A, B)

Equus niobrarensis HAY, 1913, U. S. Nat. Mus., Pr., vol. 44, p. 576.

Two molars were secured from the silt and clay at the base of the Cudahy volcanic ash pit. The characters of the teeth are like those of other Pleistocene species, and especially *Equus niobrarensis* Hay to which they are tentatively referred.

The LP_2 (Fig. 15B) has an anteroposterior diameter of 37.1 mm. and a transverse diameter of 17.3 mm. The LM^1 (Fig. 15A) has an anteroposterior diameter of 28.8 mm. and a transverse diameter of 28.75 mm. The protocone has an anteroposterior diameter of 13.5 mm.

Tobin fauna.—A local fauna taken from sec. 35, T. 14 S., R. 11 W., Russell County, Kansas, Locality No. 4, from the gray to greenish-gray silt and fine sand beneath the Pearlette ash member of the Meade formation (note measured section). The Tobin fauna is considered as contemporaneous with the Cudahy of Meade and Clark counties, Kansas, on the basis of associated invertebrates and vertebrates.

Phylum MOLLUSCA

Abundant shells of gastropods occur below the Pearlette ash in the gray silt. Associated with these invertebrates were the vertebrate remains. The associated invertebrates were reported by Leonard (Frye *et al.*, 1943, p. 40, 41).

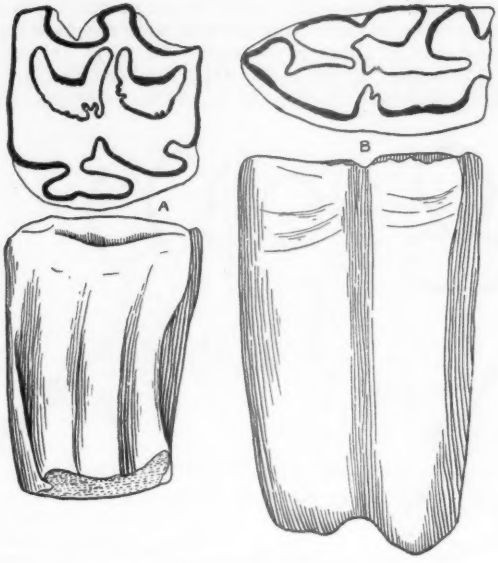

FIGURE 15.—*Teeth of* Equus *cf.* niobrarensis *Hay*
(A) KUMVP 3967, LM^1. (B) KUMVP 3967, LP_3. Lateral and occlusal views. X1

Phylum CHORDATA

Subphylum VERTEBRATA

A detailed account is given of the mammals only, though the occurrence of other vertebrates is noted.

Class PISCES

A few small fish vertebrae were found to occur in the deposit.

Class AMPHIBIA

Limb bones and vertebrae, of small frogs were found. Many of them are badly broken.

Class REPTILIA

A single vertebra was found belonging to a small lizard or snake.

Class AVES

Only one fragmentary bird bone was recovered.

Class MAMMALIA

Order RODENTIA

Family GEOMYIDAE

Parageomys n. gen.

GENOTYPE: *Parageomys tobinensis* n. sp. No. 6652, Kansas University Museum of Vertebrate Paleontology; incomplete left ramus with P_4, M_1, and M_2.

DIAGNOSIS: A small gopher which has a P_4 with a continuous enamel band around the anterior (loph) half of tooth, continuous across external and internal re-entrant angles and anterior side of posterior (loph) half of tooth and a posterior enamel plate (Fig. 16B). The tooth has the same general shape as that of *Thomomys*. Re-entrant angles of P_4 broad and not compressed as in *Geomys*. Enamel plates present only on back side of M_1 and M_2. Molars not elliptical as in *Geomys* but with

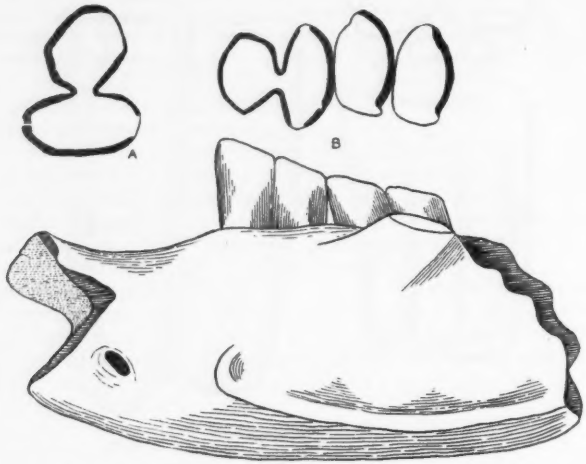

FIGURE 16.—*Ramus of* Parageomys tobinensis *n. gen., n. sp.*

(A) Paratype, KUMVP 6696, right P_4, occlusal view. ×10. (B) Holotype, KUMVP 6652, left ramus, P_4-M_2. Lateral and occlusal views. ×8.

labial sides broad. The enamel plate ends abruptly producing a slight ridge where it joins the dentine. The presence of the continuous enamel border around the anterior half of P_4 distinguishes this gopher from other known living and fossil forms.

Parageomys tobinensis n. sp.

(Fig. 16A, B)

HOLOTYPE: No. 6652, Kansas University Museum of Vertebrate Paleontology, incomplete left ramus with P_4, M_1, and M_2. Paratype right P_4, (Fig. 16A), No. 6696, Meade County, Kansas, Locality No. 17, Cudahy fauna.

HORIZON AND TYPE LOCALITY: Pleistocene, Meade formation, Russell County, Kansas, Locality No. 4, Tobin fauna.

DESCRIPTION OF TYPE: An incomplete left ramus of a small gopher. The shape of P_4 corresponds more nearly to that of *Thomomys* than *Geomys*. The re-entrant angles are broad and not compressed. A continuous enamel border is present around the anterior border of P_4 and the re-entrant angles. The posterior part of the tooth is like that of *Geomys*. Only posterior enamel plates present on M_1 and M_2. The attachment of the masseteric muscle does not extend farther forward than the anterior border of the external re-entrant angle of P_4 which is posterior to the attachment found in *Geomys*. The mental foramen is situated approximately as in *Geomys* though slightly more ventrally placed. Anteroposterior diameter of P_4-M_2 is 5.0 mm. A well-developed pit is present opposite M_3. The tize may be due to its being an immature specimen. The gopher is one of the few rodents in which she jaw and dentition increase considerably in size with age.

Genus *Geomys*

Geomys RAFINESQUE, 1817, Am. Monthly Mag., vol. 2, no. 1, p. 45.

A number of isolated premolars and molars and one upper incisor, collected in association with *Parageomys*, belong to this genus. The teeth seem to belong to a form smaller than that now found living in the area.

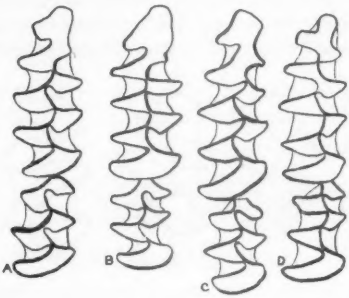

FIGURE 17.—*Lower dentitional pattern of* Microtus paroperarius *and* Pitymys meadensis

Microtus paroperarius, (A) KUMVP 6645, RM_1-M_2. (B) KUMVP 6646 RM_1-M_2. (C) KUMVP 6647, RM_1-M_3. (D) *Pitymys meadensis*, KUMVP 6304, RM_1-M_2. Occlusal views. ×10.

Family CRICETIDAE

Microtus paroperarius Hibbard

(Fig. 17A–C)

1 Five fragmentary rami, bearing teeth, of this vole were taken from the deposit in the summer of s942. The dental pattern is like that of the type from the Cudahy fauna, Meade County. The ipecimens from Russell County average slightly smaller. The right ramus, No. 6645, contains the ncisor and M_1-M_2 (Fig. 17A). The anteroposterior diameter of the two molars is 4.1 mm. No. 6646 (Fig. 17B) is a right ramus with incisor, M_1-M_2. The anteroposterior diameter of M_1-M_2 is 4.0 mm. No. 6647 is a right ramus containing the incisor, M_1, and M_2 (Fig. 17C). M_1 and M_3 have an anteroposterior diameter of 4.4 mm. No. 6648 is a fragmentary right ramus bearing M_1; and No. 6649 is a fragmentary left ramus bearing M_1. A number of isolated teeth were recovered, among which are a number of first lower molars belonging to this form.

Pitymys meadensis Hibbard

(Fig. 17D)

A right ramus, No. 6304, having the incisor, M_1, and M_2 of this form was recovered from the deposit in September, 1941. The anteroposterior diameter of M_1-M_2 is 4.1 mm. A number of isolated lower first molars were recovered from the silt. It is impossible at present to determine whether the other isolated molars belong to *Microtus* or *Pitymys*. Specimen No. 6304 (Fig. 17D) has a narrower and smaller anterior loop than the other specimens from the Cudahy fauna, due to the deeper development of the fifth internal and fourth external re-entrant angles.

At the time this ramus was found it was the only *Pitymys* known from the silt below the Pearlette ash in Russell and Lincoln counties and was unknown from Meade county. *Microtus paroperarius* was known only from Meade County by a single ramus. This apparent difference between the fossil microtines of the two widely separated deposits, as well as the difference between the *Sorex*

ramus recovered with the Wilson Valley fauna and the *Microsorex* recovered with the Cudahy fauna, accounts for the hesitancy in correlating the deposits when these fossils were first reported.

Microtus sp. and *Pitymys* sp.

(Fig. 18A-E)

In the collection are two fragmentary maxillaries bearing M^1 that are referred to *Microtus*. Since these were not found associated with the lower jaws it is impossible to assign them with certainty to *Microtus paroperarius*. No. 6650a is a fragmentary right maxillary. The anteroposterior diameter

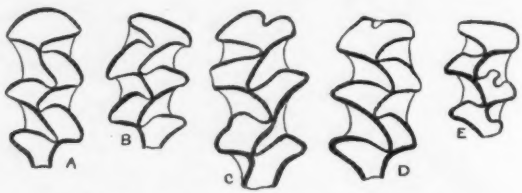

FIGURE 18.—*Upper molars of* Microtus *and* Pitymys

(A) ? *Microtus*. KUMVP 6650a, RM^1. Occlusal view. ×10. (B) ? *Microtus* KUMVP 6650b, LM^1. Occlusal view. ×10. (C) *Pitymys nemoralis*, KUMVP 1050, LM^1. Recent, Douglas Co., Kansas. Occlusal view. ×10. (D) ? *Pitymys*. KUMVP 6651, RM^1. Occlusal view. ×10. (E) *Pitymys nemoralis*. KUMVP 6053. Recent, Douglas Co., Kansas. Occlusal view. ×10.

of M^1 of this specimen is 2.4 mm. (Fig. 18A). No. 6650b is a fragmentary left maxillary bearing M^1. The pattern of M^1 (Fig. 18B) differs slightly from the preceding M^1 in that the anterior loop has a flattened anterior face instead of rounded. The first alternating triangle is not completely closed off from the anterior loop. This difference in the two specimens may be age and individual variation; again the maxillaries may belong to two distinct forms.

A fragmentary right maxillary containing M^1, No. 6651 (Fig. 18D), was recovered in association with the two maxillaries reported above. It differs considerably in that the anterior loop has an anterior re-entrant angle, filled with cement, that extends to the base of the tooth. This condition is not common in microtines. Of the larger number of recent and fossil microtine teeth examined I have found only one genus, *Pitymys*, that has an M^1 with a re-entrant angle along the face of the anterior loop, and in this case it was not filled with cement. This condition occurs in a recent specimen, K.U. No. 1050, from Douglas County, Kansas (Fig. 18C). A re-entrant angle was also observed along the face of the second alternating triangle of M^2 in a recent specimen (Fig. 18E) from Douglas County, Kansas. The finding of this condition in specimens of recent *Pitymys* does not mean that the fossil tooth having such characters is also *Pitymys*, though possibly it belongs to *Pitymys meadensis*.

DISCUSSION: The Tobin fauna on the basis of *Parageomys tobinensis*, *Microtus paroperarius*, and *Pitymys meadensis* is considered as contemporaneous with the Cudahy fauna from Meade and Clark counties. To date the vertebrates from the Tobin deposit are but slightly known.

Wilson Valley fauna.—The associated mollusks and vertebrates are here referred to as the Wilson Valley fauna which is a local fauna from Lincoln County, Locality No. 4, Kansas, taken in sec. 28, T. 13 S., R. 10 W., just below the Pearlette ash member of the Meade formation from a gray sandy silt. On the basis of the fossils the Wilson Valley fauna is considered as contemporaneous with the Cudahy and Tobin faunas.

Class MAMMALIA

Order INSECTIVORA

Family SORICIDAE

Sorex cinereus Kerr

(Fig. 19A)

Sorex cinereus KERR, 1792, Animal Kingdom, p. 206.

Approximately 1 foot below the ash there was taken a right lower ramus, No. 6183, bearing M_1-M_2 (Fig. 19A) of a small shrew which is considered as belonging to the above species. When this

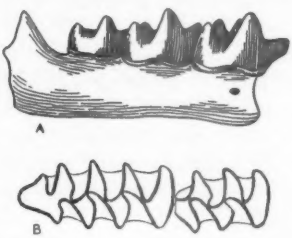

FIGURE 19.—*Rami of* Sorex cinereus *Kerr and* Microtus paroperarius *Hibbard*

(A) *Sorex cinereus*, KUMVP 6183, right ramus, M_1-M_2. Lateral view. (B) *Microtus paroperarius*, KUMVP 6298 left M_1-M_2. Occlusal view. ×10.

form was previously reported (Frye, *et al.*, 1943) it was considered as different from other fossil *Sorex* known from Kansas. During the summer of 1942, 31 rami referable to this form were recovered from an equivalent horizon in Meade County (Cudahy fauna). Only two of the rami, Nos. 6576 and 6631, compare with this specimen. It is larger than the other 29 rami of *Sorex cinereus* taken with the Cudahy fauna and those previously recovered from the younger Jones fauna. It has a mental foramen that is located more posteriorly than in the other fossil forms of this species. At present it is not known whether the differences are racial or only individual variation.

Order RODENTIA

Family CRICETIDAE

Synaptomys (*Mictomys*) *borealis* (Richardson)

Arvicola borealis RICHARDSON, 1828, Zool. Jour., vol. 3, p. 517.

Isolated teeth, No. 6682, of this form were taken from the deposit and are the same as those from the Cudahy fauna (Fig. 10F).

?Phenacomys

Two small rooted M^2 are questionably referred to the above genus. The teeth compare in size and pattern with those of forms now found living to the north and northwest. It is impossible to make comparison with *Phenacomys primaevus* Hibbard from Meade County, since the latter is known only from lower dentitions.

Microtus paroperarius Hibbard

(Fig. 19B)

Two fragmentary left rami and a number of isolated molars of this vole were recovered from the deposit. They agree in dental pattern with those from the Cudahy and Tobin faunas. Ramus No. 6298 (Fig. 19B) contains M_1 and M_2; their anteroposterior diameter is 4.0 mm. Specimen No. 6299 contains M_1, its anteroposterior diameter is 2.6 mm.

DISCUSSION: This deposit and the one containing the Tobin fauna have not been thoroughly worked and many more vertebrate forms should be found. The presence of *Sorex cinereus*, *Synaptomys borealis*, and *Microtus paroperarius* in the Wilson Valley fauna is evidence of a fauna contemporaneous with the Tobin and Cudahy faunas.

Correlation of the Cudahy, Tobin, and Wilson Valley faunas.—One is unable to correlate these local faunas with other Pleistocene faunas, because only small forms have been recovered.

In the correlation of Pleistocene faunas, the fauna as a whole must be considered, since one does not know whether he is dealing with a glacial, interglacial, or transitional fauna. When more complete faunas are known and their relative stratigraphic position is also known, we will be much better able to understand the successional changes that took place in the nonglacial areas. Such knowledge will probably show that certain index forms existed during certain Pleistocene stages and that these can be used for definite correlation.

The microtines show some evidence of being related to the forms from the Port Kennedy Bone Deposit. The fossil *Microtus* and *Pitymys* from the Cudahy fauna appear to be more closely related to some of the forms from the upper Freshwater Bed at West Runton, Norfolk, England, of upper Pliocene or Cromerian (*fide* Hinton) than to any fossil forms known in America. However, the associated forms from the British deposit indicate an entirely different environmental condition from that in Kansas at the time these forms inhabited the region.

Since these faunas were taken just beneath the volcanic ash, it might be assumed that they are equivalent in age to fossils recovered from other deposits of the High Plains that are collected from just below the volcanic ash, and especially to those in Nebraska where the ash is well known and where many fossils have been collected from deposits below the ash horizon. The evidence at hand seems to be to the contrary.

A comparison of the fossils recovered from below the ash deposits in southwestern Kansas, with the fossils reported as occurring below the ash in Nebraska, indicates the presence of at least two volcanic ash horizons in the Pleistocene of the High Plains.

Lugn and Schultz (1934, p. 359), Lugn (1935, p. 132, 134; 1939, p. 859; 1941, p. 33), and Condra and Reed (1943, p. 9) either describe or mention a volcanic ash that occurs at the top of the lower, or valley, phase of their Loveland formation. The ash occurs above their Illinoian glacial stage and at the base of their Loveland loess at the beginning of their Sangamon interglacial stage.

Lugn (1941, p. 33) states, "Volcanic ash or pumicite occurs at the base of the loess phase of the Loveland quite generally in Nebraska and Kansas." He does not cite any definite locality in Kansas, but there are numerous ash deposits in the State not

yet studied that may prove to be equivalent to the ash in Nebraska which occurs at the base of their Loveland loess. Possibly the deposits of ash that occur above the Pearlette member of the Meade formation, now considered to be reworked, may be a channel deposit of another ash fall, and thus equivalent in age to the ash in the base of the loess of Nebraska.

On the basis of fossil evidence it is impossible to consider the deposits producing the Cudahy, Tobin, and Wilson Valley faunas as equivalent in age to the deposits directly below the ash in Nebraska. Lugn and Schultz (1935, Table D) report *Mylodon* and *Equus* as occurring chiefly in deposits of their Upland formation which occurs below the ash. However, in southwestern Kansas *Mylodon* has been taken only in deposits above the volcanic ash, and *Equus* is also more abundant in deposits in Kansas above the ash than below.

It will not be possible to correlate the beds either below or above the ash until each exposure containing ash deposits, together with the beds above and below it, and their included fossils have been carefully studied.

Environmental conditions.—As previously pointed out the fossils appear to have accumulated in basins containing water or in slow-moving streams as indicated by the abundance of invertebrates, fish remains, and the type of ash deposits. The abundance of plant remains in some areas and the presence of iron concretions, as well as the stained fossils, indicate local swampy conditions.

Of the 14 mammalian genera recovered in the Cudahy fauna, only 2 are extinct (*Parageomys* and *Cudahyomys*). The recent forms of *Synaptomys borealis*, the *operarius* group of *Microtus*, *Sorex*, *Neosorex*, and *Microsorex* are confined chiefly to the Boreal region, although their range extends southward into the border of the transitional zone of the Austral region. *Ondatra*, *Citellus*, and *Peromyscus* have races that extend northward into the Boreal region. The known distribution of recent forms of *Geomys* and *Pitymys* does not extend north out of the Austral region.

The abundance of the *Sorex* and the associated *Neosorex*, *Microsorex*, *Synaptomys borealis*, and *Microtus* of the *operarius* group indicate that at the time they lived in southwestern Kansas the climate was considerably cooler and more humid than at present. This conclusion is based upon the habitats in which their nearest living relatives are found. Not only are they found chiefly in the Boreal region but in the more humid and shaded areas of that region especially around swamps, bogs, and moist meadows along streams.

In comparison to the Borchers fauna taken in the same area, the Cudahy seems to be at least in part a glacial fauna. Whether the remains are those of animals that lived in that area during a glacial stage or whether they are the remains of the last survivors of a glacial fauna that became stranded cannot be determined with certainty. The presence of *Peromyscus* suggests that they may have lived in the area at the close of a glacial stage. The *Peromyscus* jaw and the jaw of *Cudahyomys* are not stained, but white, and come from the basal ash which seems to have protected them from the acid water. These two forms may have been early invaders from a more southern fauna. The fossil *Pitymys* appears to have been associated with forms that were adapted to a cooler habitat than *Pitymys* now inhabits. In fact the identity of the fossils assigned to the genus *Pitymys* can be questioned.

There are other indications of a cooler climate in that area prior to the time when the deposits containing the Cudahy fauna were laid down. *Pliolemmus antiquus*, *Phenacomys primaevus*, and *Pliopotomys meadensis* were recovered in Meade County at the contact between the deposits of the Rexroad member of the Ogallala formation and the basal Meade sand and gravel. Two of these forms definitely indicate a cooler climate than now exists in that area. In the sand and gravel striated pebbles have been recovered from the consolidated beds (Pl. 1, fig. 2) which indicate glacial conditions in the Rocky Mountain region prior to their deposition. These pebbles are assumed to have been deposited by streams from the melting ice. Whether the beds between the sand and gravel and the overlying ash were deposited at the close of a glacial stage is not known, but to date no fossils are known from them, and they appear as one continuous deposition. At least no soil zone is known that would indicate an interglacial stage between the sand and gravel and the base of the ash. For this reason it seems evident that the Cudahy, Tobin, and Wilson Valley faunas lived in western Kansas near the close of a glacial stage. The overlying Borchers fauna is an interglacial fauna, and to date no species are known common to the two faunas.

PEARLETTE ASH MEMBER OF THE MEADE FORMATION

Cragin (1896, p. 54) described the Pearlette ash as a formation and considered that locally it graded imperceptibly into the overlying Kingsdown deposits. Smith (1940, p. 112, 118) included lenticular beds of volcanic ash within his Kingsdown in Clark County. A section studied by Smith containing the ash is now known to be a part of the Meade formation which is overlain by the lower Kingsdown silt. At this locality 2 to 4 inches of blue-gray silt occurs directly below the ash. From this silt were collected the same invertebrates and vertebrates that constitute the Cudahy fauna in Meade County. The same fossils were also collected from below the ash in sec. 11, T. 30 S., R. 23 W., about three-fourths of a mile to the northwest. At these localities buff silt, of lower Kingsdown age, is channeled into the ash. At no place have I observed the Pearlette ash grading upward into the lower Kingsdown silt.

At the type locality of the Meade formation the ash grades upward into clay. At the type locality more than 25 feet of beds conformably overlay the ash, but to date these beds have not been recognized with certainty outside of the Meade basin. Probably much of the Pearlette ash was removed by erosion, and a few exposures contain redeposited ash. Such a deposit is well exposed along the road in sec. 36, T. 30 S., R. 28 W., Meade County, just north of the Cudahy mine.

Only one vertebrate fossil has been taken from the Pearlette ash, a synsacrum of a bird recovered at the Cudahy mine in Meade County.

In regard to the accumulation of the ash deposits in the Meade formation two points of view have been expressed. Landes (1928, p. 16) regards the deposits of Pleistocene ash in Kansas as eolian. Smith (1940, p. 120) considered both wind and water transportation to be important with the final deposition in a body of quiet water. The fossils found at the base of the ash and the prevalent type of bedding clearly substantiate Smith's conclusions. Fine silt was found at all but one of the

localities studied. The fine silt is either blue gray, tan gray or brown gray and contains iron concretions; above this silt is a gradational zone, from 4 to 12 inches thick, consisting of intermixed silt and volcanic ash. From this gradational zone and underlying silt the abundant remains of invertebrates and some vertebrates were collected. From a study of the Cudahy fauna the mammals lived in and around a marshy habitat. Fish remains clearly indicate the presence of water.

It appears that the invertebrates were trapped and killed at the time of the primary ash deposit. No complete vertebrate remains or associated bones have been recovered to date, which indicates that the forms were not trapped. From a study of the deposits it appears that considerable mixing of the silt with the ash took place before the secondary accumulation of ash, possibly due to wave action. A few feet above the base of the ash in the Sunbrite mine in Meade County there is a widespread horizon of cemented ripple-marked ash (Pl. 1, fig. 1). The secondary accumulation of the ash in the still water must have been laid down in a rather short time since it is nonfossiliferous and free from silt.

The following volcanic ash localities in Oklahoma and Kansas were studied during the season of 1942 and are considered to be the Pearlette ash member of the Meade formation on the basis of the underlying silt, which contains iron concretions and in most places invertebrates and some vertebrate remains.

OKLAHOMA:

Beaver County

NW¼, sec. 8, T. 5 N., R. 28 E.

S½, sec. 6, T. 5 N., R. 28 E.

SW¼, sec. 5, T. 5 N., R. 28 E. Ash 40 feet thick. These beds dip steeply toward the Cimarron River.

KANSAS: (west to east)

Seward County

Sec. 13, T. 33 S., R. 32 W.

Sec. 19, T. 32 S., R. 33 W. This is either a stream deposit or reworked ash.

E½, sec. 24, T. 32 S., R. 33 W. Ash 4 to 5 feet thick, unconformity above, valley fill channeled into ash. Blue-gray silt at base with rusty concretions.

E½, sec. 34 and W½, sec. 35, T. 33 S., R. 32 W. The ash at this locality is considered to have been deposited in running water. A stream of considerable size.

Grant County

Sec. 24, T. 30 S., R. 35 W.

Meade County

Sec. 33, T. 30 S., R. 26 W.

Secs. 2, 11, 12, and 13, T. 31 S., R. 28 W. Cudahy fauna in silt below ash.

Sec. 33, T. 31 S., R. 28 W. Cudahy fauna in silt below ash. Smith (1940, p. 119) questions the age of this ash and considers it may be as old as the Tertiary. The dipping of this deposit is due to the Crooked Creek fault.

Sec. 9, T. 32 S., R. 28 W.

Secs. 23 and 26, T. 32 S., R. 28 W. Cudahy fauna in silt below ash.

Secs. 16 and 21, T. 33 S., R. 28 W.

Clark County

Secs. 1, 8, 11, 12, and 17, T. 30 S., R. 23 W. Invertebrates and vertebrates in silt below ash that are the same as the Cudahy fauna.

Sec. 19, T. 30 S., R. 23 W.

Secs. 23 and 24, T. 30 S., R. 24 W.

Comanche County

Sec. 12, T. 31 W., R. 18 W. Blue or green-gray silty clay below ash. Thickness of ash reported from core drill as 22 feet.

Russell County

Sec. 35, T. 14 S., R. 11 W. Invertebrates and vertebrates in silt below ash, Tobin fauna, same as Cudahy fauna.

Lincoln County
Sec. 28, T. 13 S., R. 10 W. Invertebrates and vertebrates in silt below ash, Wilson Valley fauna, same as Tobin and Cudahy faunas.

Other ash deposits in Kansas should not be assumed to be of the same age as the ash in the Meade formation until they are carefully studied and so proved. It is not known whether one or more ash falls existed in the Pleistocene of this area; also, reworked ash occurs in younger deposits. If it is shown that the ash deposits in Kansas or all those in southwestern Kansas are the same age unless redeposited there will be established one of the best stratigraphic markers known in the Pleistocene of the High Plains.

BEDS OF MEADE FORMATION ABOVE THE PEARLETTE ASH MEMBER

General statement.—At the type locality of the Meade formation in sec. 21, T. 33 S., R. 28 W., in Meade County there is exposed 32.7 feet of beds above the Pearlette ash. These beds consist chiefly of silt, clay, and sandy silt. They have not been recognized in any other exposure of the Meade formation.

Borchers fauna.—At this locality above the ash there was collected from the gray silt and clay a large number of vertebrates known as the Borchers fauna. To date no vertebrates or invertebrates have been found above the ash in Kansas that are equivalent to this fauna. Following is a list of the forms known from the Borchers fauna which are considered as interglacial. For a complete discussion of these *see* Hibbard (1941; 1942; 1943).

AMPHIBIA:
Amphibian remains

REPTILIA:
Reptile remains

AVES:
Numerous bird remains

MAMMALIA:
Insectivora
Sorex taylori Hibbard
Carnivora
Canis sp.
Mustela sp.
Felis? sp.
Rodentia
Ciiellus meadensis Hibbard
C. cragini Hibbard
Geomys sp.
Etadonomys tiheni Hibbard
Perognathus gidleyi Hibbard
P. pearlettensis Hibbard
Onychomys fossilis Hibbard
Reithrodontomys pratincola Hibbard
Sigmodon hilli Hibbard
Parahodomys sp.
Synaptomys cf. *vetus* Wilson
Ondatra sp.
Zapus burli Hibbard
Lagomorpha
Nekrolagus sp.
Hypolagus sp.
Lepus cf. *californicus* Gray
Perissodactyla
Equus sp.
Artiodactyla
Camelops sp.
Antilocaprid sp.

DISTRIBUTION AND CORRELATION OF THE MEADE FORMATION

The Meade formation and beds of equivalent age occur over a large area in southwestern Kansas, particularly in Meade, Clark, Grant, Seward, Ford, Kiowa, and Comanche counties, and as terrace and high-level valley fill deposits in central Kansas. Seemingly, the depositing streams of this age in southwestern Kansas and the Oklahoma Panhandle were not confined in definite bedrock valleys but spread their sediments over large basinal areas, particularly the Meade and related basins, thus

building up a thick sequence of beds alternating from coarse channel gravels to fine-textured flood-plain deposits. Volcanic ash falls occurred over much of this area and were concentrated by stream action and sheet wash in shallow flood-plain lakes and sluggish channels. In central Kansas, beds here tentatively correlated with the Meade formation were deposited in broad bedrock valleys which for the most part were subsequently dissected by stream erosion. Volcanic ash was also deposited over this area but was concentrated in much smaller lentils in flood-plain ponds or oxbows.

Although the deposits in McPherson County, referred to by Lohman and Frye (1940, p. 840, 851) and Frye and Hibbard (1941a, p. 268) as the McPherson (restricted) formation are probably equivalent in age to part of the Meade formation no definite correlation has been made here because correlative faunas have not been collected from it. The vertebrates collected from the type locality of the McPherson (restricted) formation are all large mammals, and the type of collecting necessary to recover the small forms, which form such a prominent part of the Cudahy and equivalent faunas, has never been carried on in that area. It is probably advisable to retain the term McPherson formation as a local name for these channel-fill deposits until more adequate fossil data have been obtained. Also the stratigraphic relationship of the volcanic ash, above the stream-laid McPherson beds and below the widespread loess, is not completely understood. It may prove to be equivalent to the ash overlying the Cudahy, Tobin, and Wilson Valley faunas.

KINGSDOWN SILT FORMATION

GENERAL STATEMENT

Overlying the Meade formation in Clark, Meade, Kiowa, and Comanche counties, Kansas, are a series of beds known as the Kingsdown silt which contain both invertebrate and vertebrate remains.

Cragin (1896, p. 54) named and described the Kingsdown marl from exposures west of Kingsdown in Ford County, Kansas, and the upper part of Bluff Creek in Clark County. Cragin, unfortunately, did not definitely designate a type locality for his "Kingsdown Marl" which has led to the confusion of his Kingsdown formation, which he thought might be late Pliocene, with his unconformable overlying beds of sand, marl, diatomaceous earth, etc., of supposed Quaternary age. Cragin (1896, p. 53) stated, "at several localities in Kansas, typically on Bluff creek, in Clark county, in the immediate vicinity of old Vanhem postoffice, occurs a succession of three terranes." Since Cragin does not give any locality for the occurrence of the overlying beds one is at a loss to know whether he recognized such beds in the vicinity of Vanhem; if he did, they are the beds here referred to as the upper Kingsdown. However, it can be questioned since Cragin stated that the "Kingsdown Marls" are typically developed in Meade County. No beds in Meade County are known to be equivalent to the lower Kingsdown of Clark county. If Cragin did recognize the upper deposits in Clark County above the lower Kingsdown he apparently confused them with the lower Kingsdown as he passed westward into Meade County.

Location of Vanhem has led to much confusion in the field since it does not occur on the maps, and the present residents of that area settled there after the Vanhem post office was abandoned. Vanhem was located in sec. 13, T. 30 S., R. 23 W., and within three-quarters of a mile of the old post office site one may find well exposed all three formations described by Cragin.

Smith (1940, p. 111–112) considered Cragin's "Kingsdown Marl" loosely defined and redescribed it giving as a typical section, an exposure measured in sec. 13, T. 30 S., R. 23 W., on the Stephenson Ranch (now Pyle Ranch). The beds described in Smith's section include only those beds referred to here as upper Kingsdown.

Frye and Hibbard (1941, p. 419–420) included Cragin's "Kingsdown Marl" and his overlying sand and silt with the loess that grades upward into deposits of recent age within the Kingsdown silt formation.

From a restudy of the entire area it is found that the "Kingsdown Marl" apparently referred to by Cragin is distinctly divisible into an upper and a lower part separated by a disconformity.

LOWER KINGSDOWN SILT

Description.—Cragin (1896, p. 54) stated that,

> "the Kingsdown Marl consisted of yellowish-brown lacustrine or slack water marls, containing variously shaped concretions of calcium carbonate and silicate of lime. They are very rarely fossiliferous. The Pearlette ash frequently passes into the Kingsdown by imperceptible gradation."

Although it is not known whether Cragin was referring to the upper or lower Kingsdown, his description more accurately applies to the lower Kingsdown beds along Bluff Creek. These beds however are separated from the Pearlette ash by a disconformity.

The lower Kingsdown consists of light-buff silt and some sand and caliche pebbles, unconformable upon the Meade formation and unconformably overlain by the upper Kingsdown silt.

The best exposure of the lower Kingsdown silt and its strategraphic relationship is on the George Taylor ranch southeast of Bloom, Kansas, in northwestern Clark County on the north side of Bluff Creek along the west side of a small tributary stream in sec. 17, T. 30 S., R. 23 W. Here the lower Kingsdown silt is channeled into the Meade formation. The ash and underlying beds have been removed down to the lower sand and gravel of the Meade formation. At this point the basal sand and gravel are consolidated in part. The deposits are mostly local in origin, for at the base of the lower Kingsdown is a thick conglomerate consisting chiefly of redeposited rubble, dominantly abraded caliche pebbles, and some gravel from the underlying Meade and/or middle Pliocene.

SECTION OF THE LOWER KINGSDOWN FORMATION

In SE¼, sec. 17, T. 30 S., R. 23W., Clark County

	Thickness (Feet)
KINGSDOWN SILT FORMATION	
Upper Kingsdown	
4. Silt, light tan, grading upward into top soil	5.0

Unconformity
Lower Kingsdown
3. Silt, thick bedded, light buff, grading into sandy silt and fine sand at base, contains some gastropods..... 20.0
2. Gravel, composed of abraded caliche, thin-bedded and cross-bedded, containing igneous rock types, at the top a thin lenticular caliche bed..... 5.0
Unconformity

MEADE FORMATION
1. Sand, medium to coarse, mortar bed near top 6 to 12 inches thick, tightly cemented fine sand, pink granite and pebbles. Base covered..... 15.0

Total thickness exposed..... 45.0

Less than 100 yards south of this exposure the upper Kingsdown silt is channeled into the lower Kingsdown silt, more than 20 feet exposed, with the two silts lying side by side and the upper Kingsdown silt extending over the section measured. The base is not exposed. A section published by Smith from sec. 13, T. 30 S., R. 23 W., in Clark County is a good example of this channeling. This section occurs along the west bluff of a north-south tributary of Bluff Creek. It consists entirely of upper Kingsdown silt resting unconformably at the base upon the basal sand and gravel of the Meade formation. From the top of this exposure one walks westward but a few yards across a flat divide, covered by buffalo grass, to drop over a small bluff consisting of lower Kingsdown silt. The two exposures seem to be continuous, and only a change in facies accounts for the difference in lithology and color, but actually the upper Kingsdown silt is channeled into the lower, and the contact is completely hidden by slump and vegetation. A careful study of the two exposures upstream reveals their true relationship.

North of the exposure on the George Taylor ranch in sec. 8, T. 30 S., R. 23 W., is a good outcrop of the lower Kingsdown silt, showing where it is channeled into the volcanic ash of the Meade formation and where the old stream failed to cut through to the underlying Meade sand and gravel.

SECTION OF THE LOWER KINGSDOWN AND MEADE FORMATIONS
In sec. 8, T. 30 S., R. 23 W., Clark County

	Thickness (Feet)
KINGSDOWN SILT FORMATION	
Lower Kingsdown	
4. Silt, light buff, containing a few scattered concretions and fragments of fossil turtle, grades upward into top soil	25.0
3. Reworked ash, interbedded with and reworked into the light buff silt	10.8
Disconformity	
MEADE FORMATION	
2. Ash, cross-bedded, weathers to form a resistant bench on north exposures, where moist covered with moss, beds dipping toward the south-east	10.0
1. Silt, sandy, reddish, in places it grades downward into a sandy silt, light tan, containing pockets of fine rusty sand. Base not exposed	16.5
Total thickness exposed	62.3

SECTION OF LOWER KINGSDOWN AND MEADE FORMATION
NE¼, sec. 11, T. 30 S., R. 23 W., on the east side of draw, Clark County

	Thickness (Feet)
Lower Kingsdown	
7. Silt, light buff, grading into top soil	0.0–3.0
Disconformity	

MEADE FORMATION	
6. Volcanic ash, weathered at top	5.0
5. Silt, fine sandy, in places near top grading into fine stream sand with few pebbles, lateral to stream sand is slack water deposit of clay, 4 to 6 inches, blue green, which contains gastropods and vertebrates equivalent to Cudahy fauna of Meade county	3.33
4. Conglomerate, grades upward into Rocky Mountain type of coarse gravels, (caliche pebbles wanting) coarse sand, medium sand, with fine sand at top	12.0
3. Conglomerate, consolidated, consisting of numerous abraded caliche pebbles, granite, quartz, quartzite, chert, and other Rocky Mountain types. Manganese-stained zones of gravel. Numerous vertebrate fragments, (*Equus* molars)	4.0
Disconformity	
2. Sand, fine	10.75
1. Sand, fine silty, reddish, base covered	1.0
Total thickness exposed	18.08

Owing to the lack of fossils and the small area exposed for study, it is not known whether the unconformity between beds two and three is the base of the Meade formation or whether it is where the channel of the stream shifted laterally across its own flood plain.

Across the draw westward and up the left fork of the draw, an exposure of reddish sandy silt with lime streaks, below the volcanic ash, resembles beds in the Meade formation in secs. 16 and 21, T. 33 S., R. 28 W., in Meade County. Farther up the draw tightly compact beds of gray silt containing a large amount of lime weather to a prominent bench. These gray beds are older than the ash, but it is not known whether they should be considered part of the Meade formation.

Downstream on the west side a short distance from the exposure of the reddish sandy silt beds below the ash there is exposed the consolidated sand and gravel of the basal Meade with the lower Kingsdown resting unconformably upon them. The lower Kingsdown here consists of gray silt and lime. In places these beds are quite fossiliferous (containing large numbers of invertebrates, especially *Lymnea stagnalis* Linnaeus), though as a rule they are as barren as the overlying light-buff silt into which they grade. These gray beds seem to have been a still-water deposit and contain much calcium carbonate. The gray beds referred to by Frye and Hibbard (1941b, p. 420) in the Kingsdown of Meade County are younger than these. The beds in Meade County were deposited in the Meade Lake at the same time or after the typical light-tan sediments were accumulating elsewhere.

Distribution.—Beds equivalent to the lower Kingsdown have not been observed in Meade County. Possibly the channel phase containing the Cragin quarry fauna and Locality No. 4 of Smith's (1940, p. 109) "*Equus niobrarensis* beds" are equivalent to the basal lower Kingsdown channel phase.

As one goes east in northern Clark County beyond where Bluff Creek swings abruptly south, the lower Kingsdown pinches out, and no exposures are seen again until nearly south of Bucklin. Here it is exposed along gulley sides in secs. 5, 6, and 8, T. 30 S., R. 21 W. The area in Clark County south of Bluff Creek was not studied. How far north and east the beds extend is not known. The most eastward exposure of the lower Kingsdown silt studied was about 2 miles northeast of Wilmore, Kansas, in Comanche County. West and a little north of this good exposure of the light-buff beds is an exposure of Pearlette ash overlain unconformably by the lower Kingsdown silt, in sec. 12, T. 31 S., R. 18 W.

The light-buff silts appear to have been local in origin and were never deposited to the west in Meade County. If they were continuous, they were eroded away. These beds are locally characterized by the rounded concretions of calcium carbonate mentioned by Cragin. The beds to date appear nonfossiliferous, as he reported, except for the few local deposits of invertebrates.

Vertebrates from the lower Kingsdown silt.—Cragin found only the remains of *Elephas* in his "Kingsdown Marl." Hay (1917), who reported upon the material collected by Cragin in 1891 from this area, does not mention *Elephas*.

Only four vertebrate fossils have been taken from these deposits by our field parties which worked the beds intensively in the summers of 1936 and 1942, besides short visits in 1937, 1938, and 1939.

Order EDENTATA

Family MYLODONTIDAE

Mylodon harlani Owen

(Fig. 20, A, F)

Mylodon harlani OWEN, 1840, Zoology of the Voyage of H.M.S. Beagle, Pt. 1, p. 68.

In sec. 11, T. 30 S., R. 23 W. an upper tooth, probably the second, No. 6514, of this sloth was taken at the top of the gray beds where they blend into the light-buff silt. The anteroposterior diameter of the tooth is 36.75 mm.; greatest transverse diameter is 18.2 mm. A distal end of the right humerus, No. 6512, was taken from the light-buff silt in the NE¼, sec. 17, T. 30 S., R. 23 W. I am indebted to Dr. Edwin H. Colbert for the identification of these specimens.

Order ARTIODACTYLA

Family ANTILOCAPRIDAE

(Fig. 20E)

The distal end of a right humerus, No. 6525, of a Pronghorn, was taken from the light-buff silt in the SW¼, sec. 12, T. 30 S., R. 23 W., Pyle ranch, Clark County. It probably belongs to the genus *Antilocapra*. It is so badly damaged that it is not possible to give accurate identification. Near it was taken a part of a lower jaw of *Equus* in one of the hard concretions.

Bone fragments have been observed in the light buff silt in sec. 11, T. 30 S., R. 23 W. in Clark County.

UPPER KINGSDOWN SILT

Description.—The upper Kingsdown silt consists of light-tan silt and fine sand, thin-bedded at the base grading upward into massive silt and loess. It unconformably overlies the lower Kingsdown. One of the best exposures of these beds is in NE¼ sec. 13, T. 30 S., R. 23 W., Clark County. A measured section is given by Smith (1940, p. 112). Here it has channeled completely through the lower Kingsdown and rests unconformably upon the basal sand and gravel of the Meade formation. The true relationship of the upper Kingsdown silt to the lower Kingsdown silt is best seen north of the George Taylor ranch house in sec. 17, T. 30 S., R. 23 W. On the basis of lithology and color the beds are distinguishable from the lower Kingsdown silt. Sand occurs at the base of the channel phase, which contains numerous

invertebrate and some vertebrate fossils. The sand grades upward into fine sandy silt and silt. The silt has a decided reddish cast in contrast with the light-buff silt of the lower Kingsdown. Both invertebrate and vertebrate fossils are far more numerous in the upper silt than in the lower. The tan silt grades upward into loess and top soil; in many places along the flood plain of the old stream it spreads out over the underlying light-buff silt.

Cragin (1896, p. 54) includes diatomaceous marl in the beds that unconformably overlie his Kingsdown Marl. I know of no deposit of Pleistocene diatomaceous marl in Clark or Meade counties, though a good deposit is exposed south of the Meade County line in Oklahoma on the north side of the Cimarron River on the XI Ranch in sec. 15, T. 6 N., R. 25 E., Beaver County, Oklahoma. This diatomaceous marl contains mollusks, ostracods, and fish remains. Above the marl in one area is a good exposure of fresh-water limestone 1 to 3 inches thick. The exact relationship of these beds in the Pleistocene section is not fully understood as it is a local deposit within a large sink. It is probable that Cragin visited this area and was referring to these beds (Cragin, 1891, p. 23).

The deposits of Kingsdown silt referred to by Frye (1942, p. 109, 110) in Meade County are entirely upper Kingsdown silt. The Jones fauna of Meade County is equivalent to some part of the upper Kingsdown silt, probably near the base; since it occurs in a local sinkhole fill its true relationship is not known.

Distribution.—These beds are widespread throughout southwestern Kansas and are chiefly confined to the uplands. Evidence of the basal channeling is not so common. The best exposure of this channeling in Meade County is 8 miles north of Meade, on the west side of the road on Kansas Highway 23.

Probably much of the upper part of local sinkhole fills in Meade County corresponds in age to the upper Kingsdown silt. Since the deposits are local in origin and fossils from them are rare, it is impossible to correlate these deposits with one another.

Vertebrates from the upper Kingsdown silt.—Amphibia and bird remains have been taken from the basal sand in Clark County on the Pyle ranch. Following is an account of the mammals collected.

Order RODENTIA

Family SCIURIDAE

Cynomys ludovicianus (Ord)

(Fig. 20C)

Arctomys ludovicianus ORD, 1815, Guthrie's Geography, 2d Am. ed., vol. 2, p. 292.

Two lower jaws, a right No. 5895 and a left No. 5896, bearing complete dentition, were taken, approximately 15 feet below the surface, from the light-tan silt in sec. 12, T. 30 S., R. 23 W. in Clark County, in 1936. Associated lower jaws and fragmentary maxillaries, No. 6710, were found in the summer of 1942 approximately 25 feet below the surface in association with remains of a peccary from the same exposure as that in which the above were taken. They are indistinguishable from the prairie dogs found living in that area at the present time.

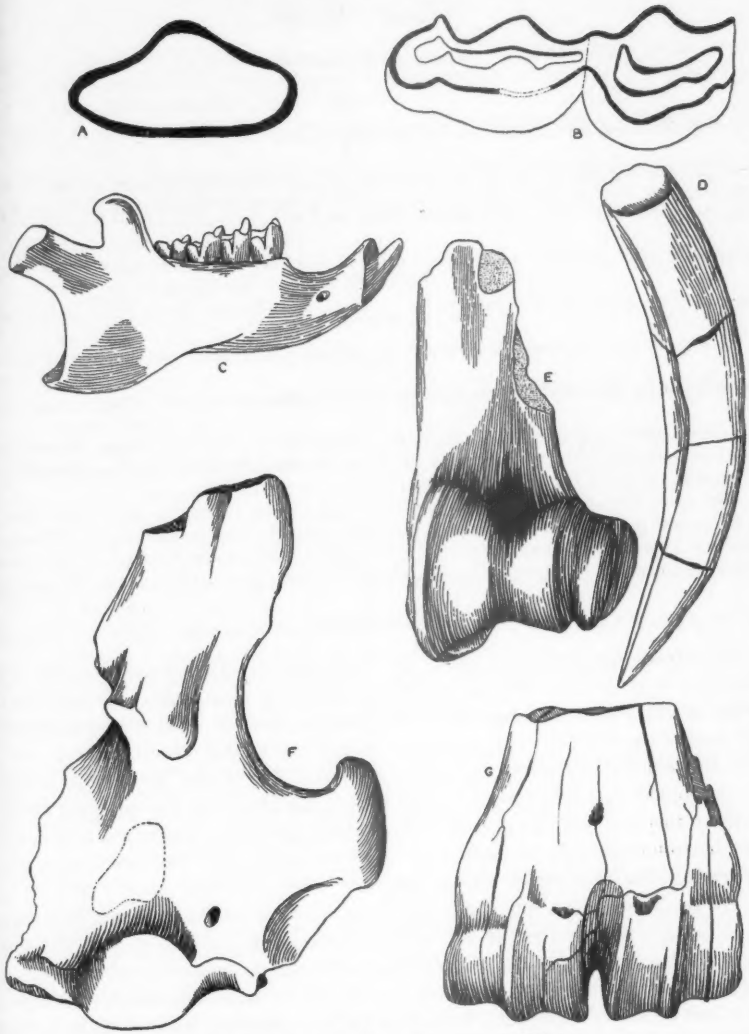

FIGURE 20.—Mylodon, Camelops, Cynomys, *and* Bison

(A) *Mylodon* sp. KUMVP 6514, upper molar. Occlusal view. ×1. (B) *Camelops* sp. KUMVP 6526, LM_3. Occlusal view. ×1. (C) *Cynomys ludovicianus* (Ord). KUMVP 5985, right ramus. Lateral view. ×1.5. (D) KUMVP 6534, peccary upper canine. Lateral view. ×1. (E) KUMVP 6525, antelope, distal end of humerus. ×1. (F) *Mylodon* sp. KUMVP 6512, distal end of humerus. ×.25. (G) *Bison* sp. KUMVP 6527, distal end of metapodial. ×.5.

Order ARTIODACTYLA

Family TAYASSUIDAE

(Fig. 20D)

A left lower canine and an incisor, No. 6534, of a peccary were taken from the light-tan silt in association with the prairie-dog, No. 6710. The teeth are probably those of *Platygonus*.

Family CAMELIDAE

Camelops kansanus Leidy

(Fig. 20B)

Camelops kansanus LEIDY, Acad. Nat. Sci. Philadelphia, Pr., vol. 7, p. 172.

A part of a fragmentary ramus, No. 6526, bearing M_3, of this camel was taken at Locality No. 5, SE¼ sec. 12, T. 30 S., R. 23 W., in Clark County from the top of the basal sand in the Upper Kingsdown silt.

Family BOVIDAE

Bison sp.

(Fig. 20G)

Bison H. SMITH, 1827, Griffith's Cuvier, Animal Kingdom, vol. 5, p. 373.

A distal end of a metacarpal, No. 6527, and three vertebrae were found within 50 yards of the camel jaw, slightly higher in the section, coming from the top of the sand. The bones belong to one of the larger *Bison*. They are well fossilized.

The upper Kingsdown silt is widespread in Meade County. The only fossil taken from the deposits in that area was a badger ramus, *Taxidea taxus* (Schreber), from the upper silt below the loess which overlies the deposit containing the Jones fauna in the Jones sink. The bed that contains the Jones fauna may be equivalent to some phase of the basal part of the upper Kingsdown silt.

SUMMARY

The Meade formation was one of the first mappable Pleistocene units described from the High Plains. The extent of the formation is unknown. It includes the oldest known Pleistocene deposits in southwestern Kansas. The sand and gravel at the base of the formation are considered as having been laid down by streams fed by melting mountain glaciers. A contemporaneous Pleistocene fauna (the Cudahy, Tobin, and Wilson Valley local faunas) occurs just below the Pearlette ash member of the formation. The combination of the fauna and the volcanic ash is one of the best horizon markers in the formation. By a careful study of these the formation can be recognized and extended with certainty.

The fauna indicates a cooler and more humid climate than now exists in that region. It is thought to have lived in that area at the close of a glacial stage. The fossils accumulated in marshy depressions filled with water, in which volcanic ash was trapped. The fossils recovered from the deposit differ from those known from the Borchers fauna, an interglacial just above the volcanic ash. None of the forms in the glacial fauna are found living in that area now, though living representatives of some of the forms are found in northern United States, Canada, and Alaska.

The Kingsdown silt formation unconformably overlies the Meade formation where both are present. The Kingsdown silt is divided into the lower and upper. Both are developed basally as channel phases. At the present time the upper Kingsdown silt is known over a much wider area than the lower. Fossils are not abundant.

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Museum of Vertebrate Paleontology, University of Kansas, Lawrence, Kansas
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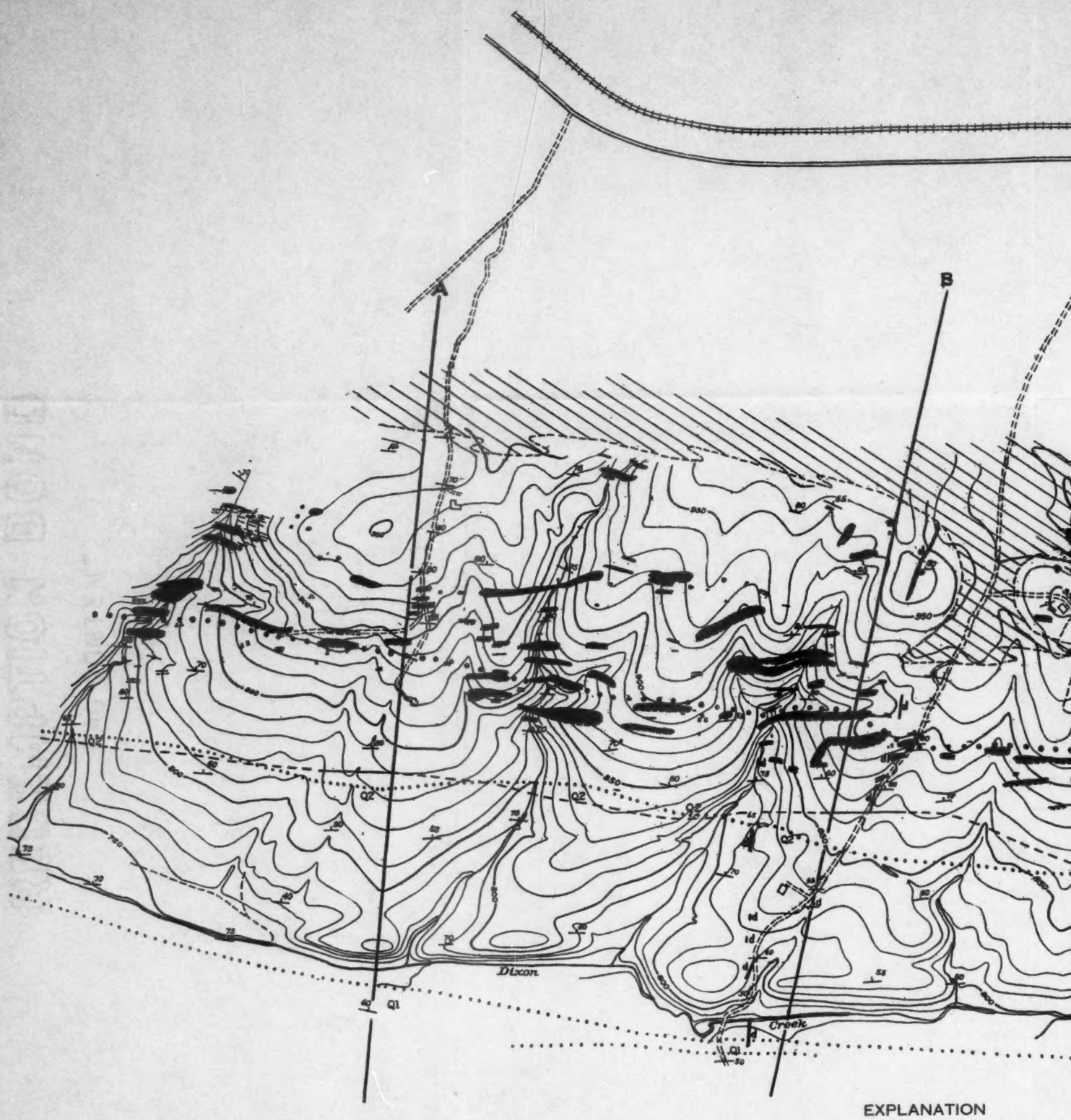
Project Grant 413/42.



EXPLANATION

Triassic diabase

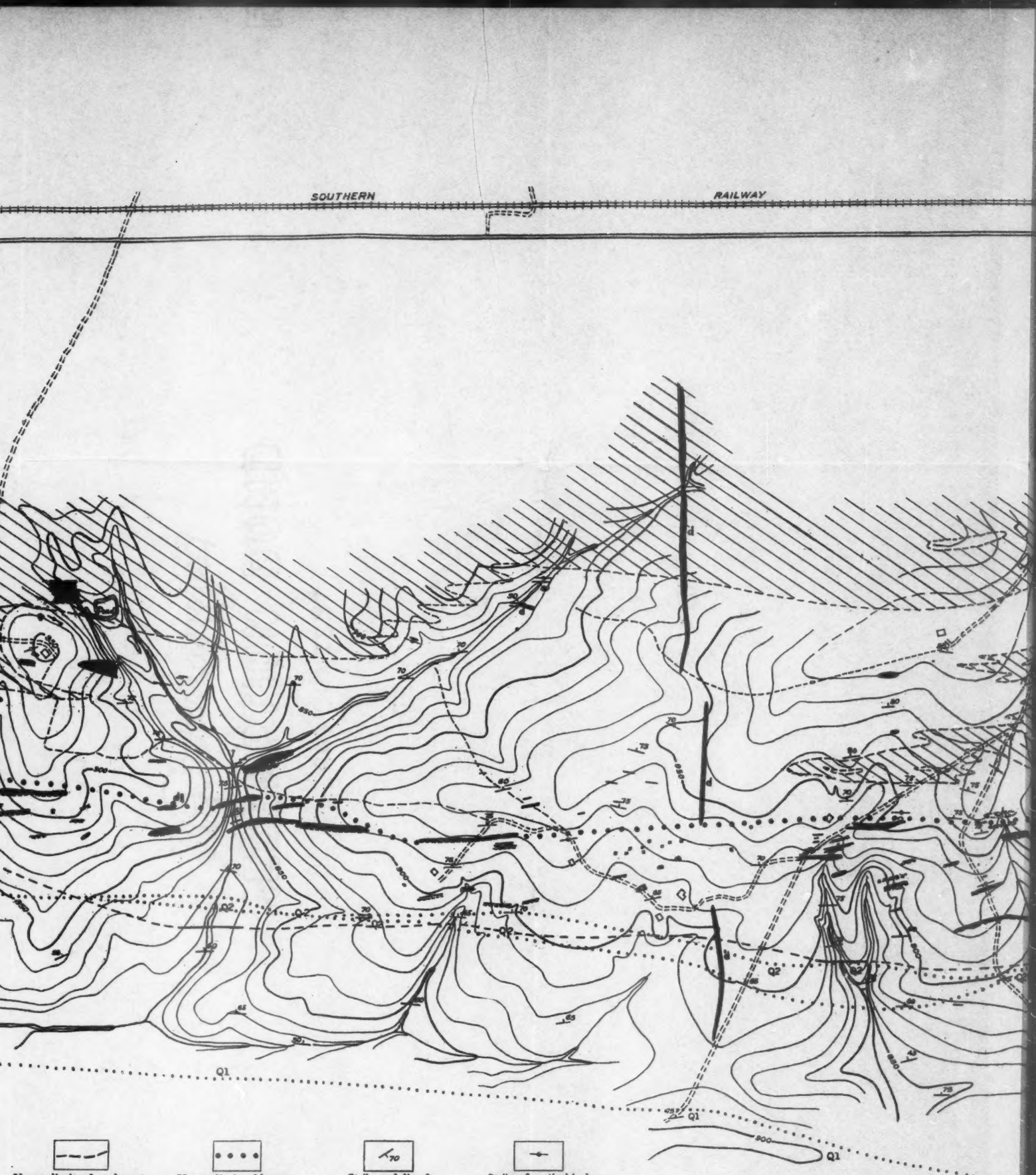
Pegmatite, probably Carboniferous
(Contains spodumene where paralleled by dashed line)

Granitic gneiss, including intrusive granite; probably Carboniferous

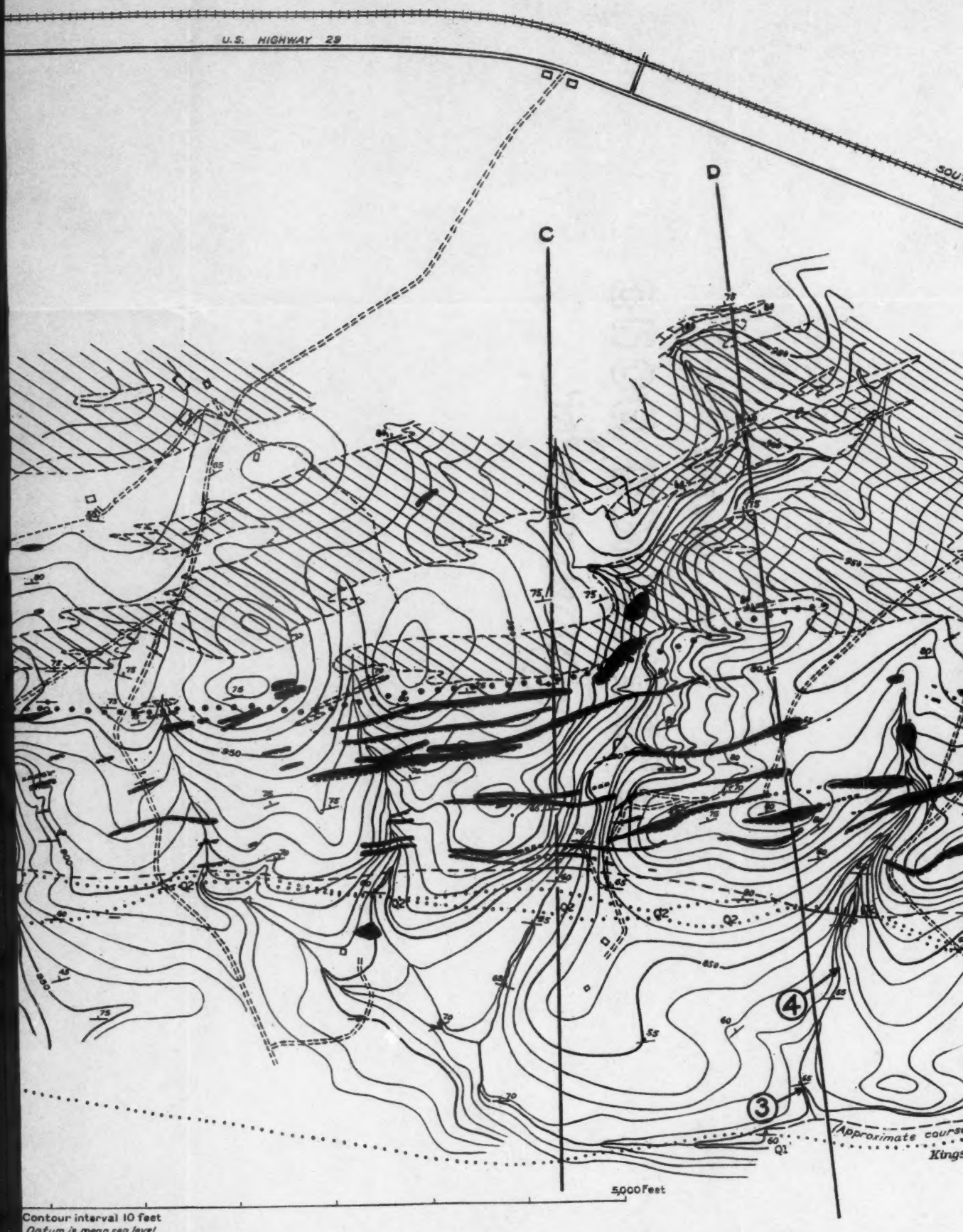
Country rocks
(Includes crystalline limestone, mica schists and gneisses, and hornblende gneiss interbedded as shown in columnar sections, plate 3, plotted along lines A, B, C, D, E, and F)

Quartzite zones
Q 1–lower
Q 2–upper

Upper
and
rock
secu
line


SOUTHERN
RAILWAY
Q1
Q2
Upper limit of carbonate and carbonate-silicate rocks; limit determined accurately where solid line is shown
Upper limit of layers of hornblende gneiss (top of Gaffney formation)
Strike and dip of beds and foliation
Strike of vertical beds and foliation
500
0
Contour interval 10 feet
Datum is mean sea level
1942

OUTLINE GEOLOGIC MAP OF THE KINGS MOUNTA



Contour interval 10 feet
Datum is mean sea level
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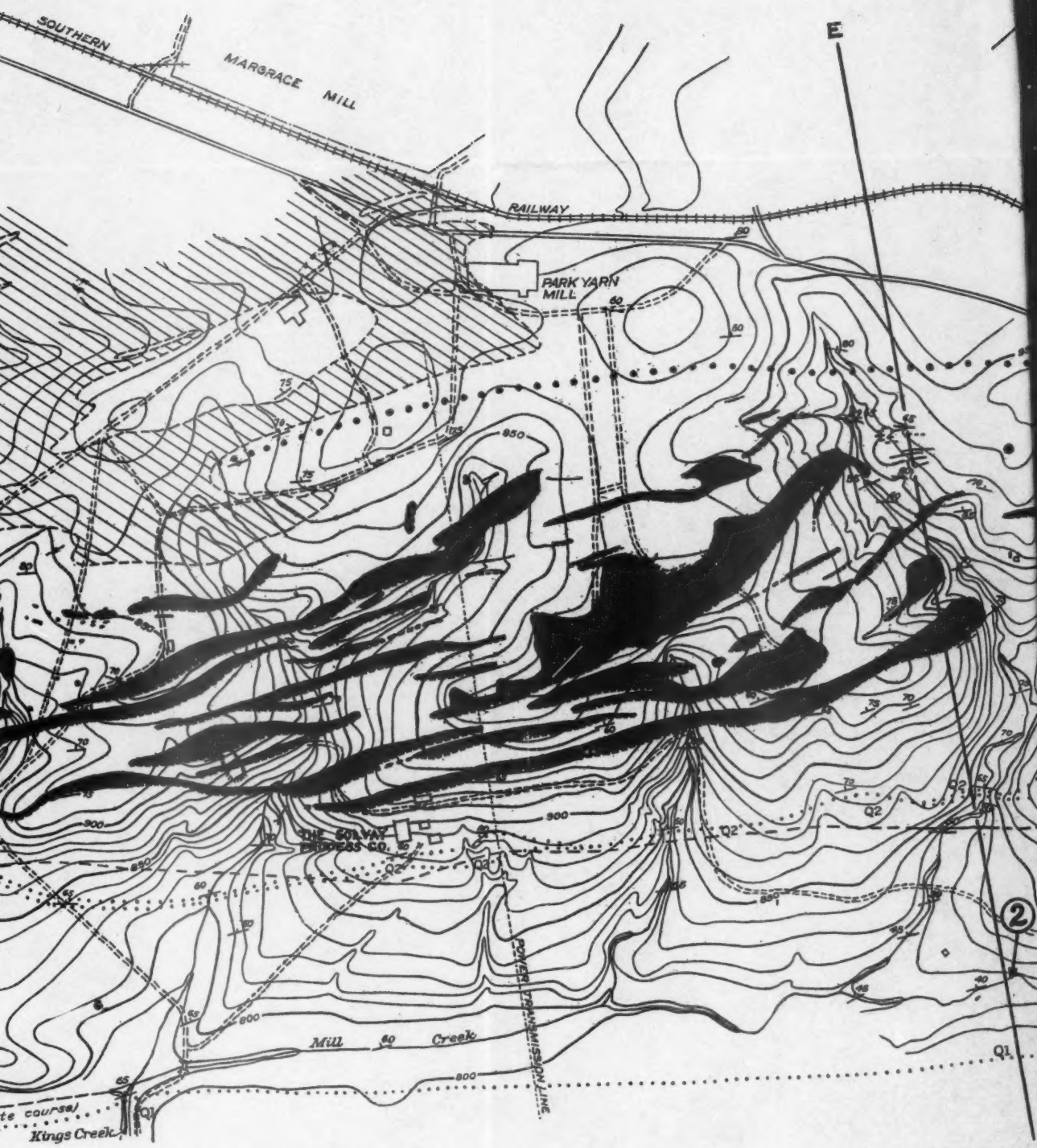
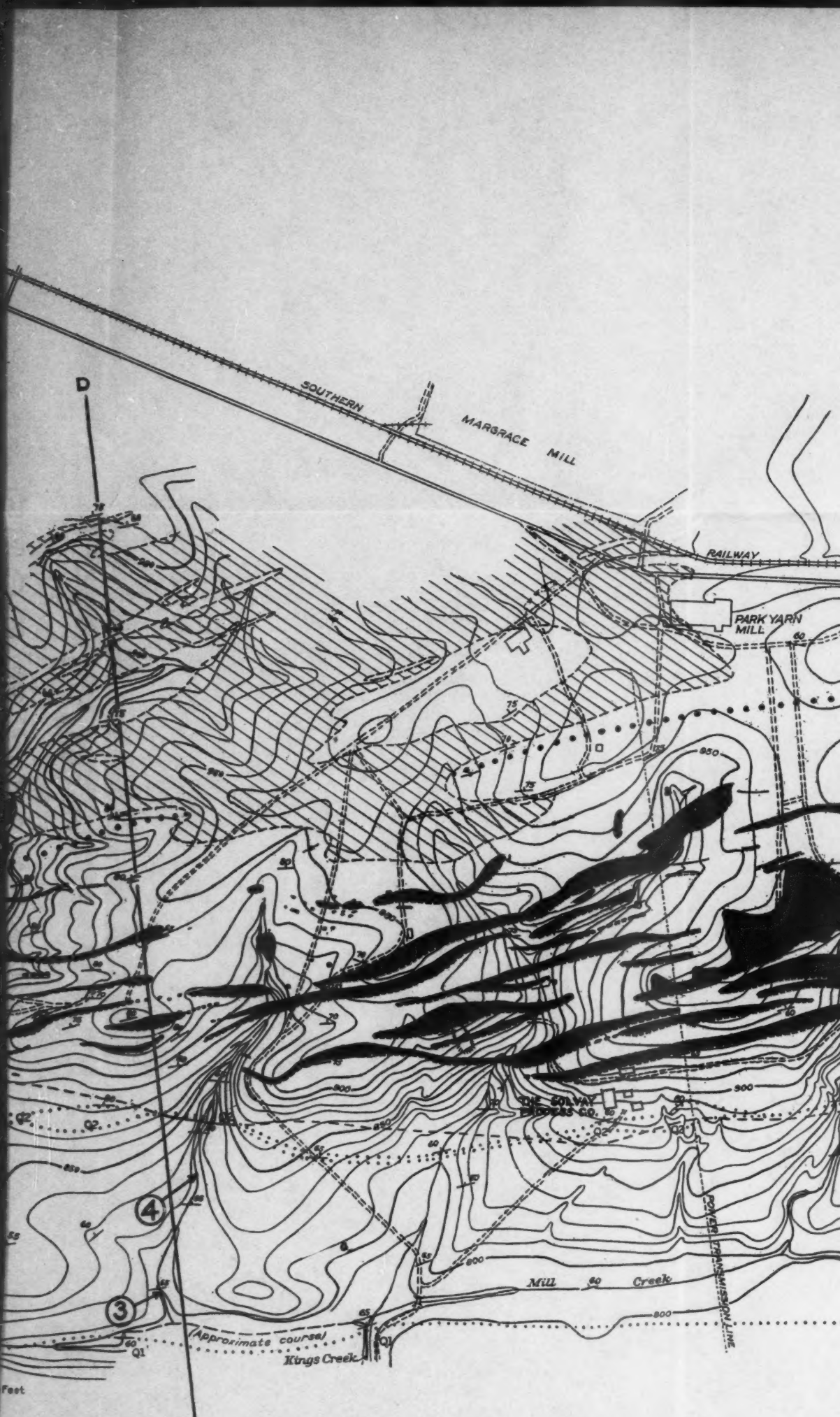
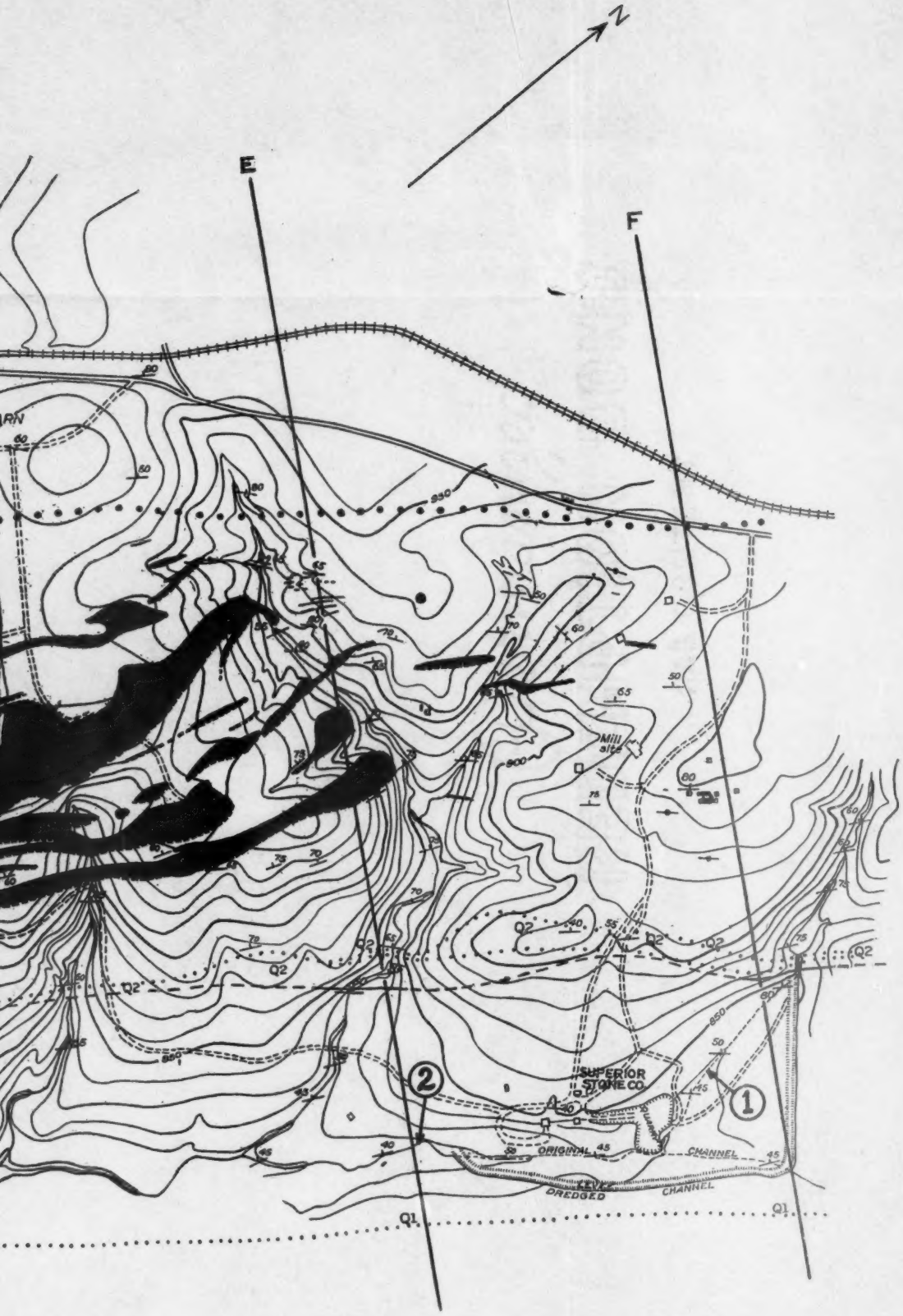
THE KINGS MOUNTAIN AREA, NORTH CAROLINA


SOUTHERN
MARGRACE MILL
RAILWAY
PARK YARN MILL
E
950
900
850
800
Q1
Q2
POWER TRANSMISSION LINE
Mill Creek
Kings Creek
2


D
SOUTHERN
MARGRACE MILL
RAILWAY
PARK YARN MILL
THE SOLWAY PAPER CO.
POWER TRANSMISSION LINE
Mill Creek
(Approximate course)
Kings Creek
Feet


N
E
F
Mill site
SUPERIOR STONE CO.
ORIGINAL CHANNEL
DREDGED CHANNEL
Q1
Q2
1
2

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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CORRELATION OF SOME METAMORPHIC ROCKS IN THE CENTRAL CAROLINA PIEDMONT

BY THOMAS L. KESLER

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ABSTRACT

A belt of the Piedmont between Lincolnton, North Carolina, and Gaffney, South Carolina, is underlain by metamorphic country rocks, granitic rocks and albitic pegmatite, and Triassic diabase. The country rocks comprise quartzite, variably micaceous crystalline limestone and dolomite, impure limestone or carbonate-silicate rocks, fine-grained mica schists and gneisses, hornblende and hornblende-biotite gneisses, and scarce pyroxene, amphibole, quartz-tourmaline, and chlorite rocks. The noncarbonate rocks, except quartzite, have been mapped as pre-Cambrian (the Carolina and Roan formations). The quartzite, carbonate-silicate rocks, and crystalline limestone have been mapped as Cambrian (the Kings Mountain, Blacksburg, and Gaffney formations).

Textures are for the most part crystalloblastic, but some varieties, particularly the carbonate-silicate, show definite evidence of sequential rather than simultaneous crystallization of the minerals; cataclastic texture is but slightly developed. The silicate minerals in the carbonate-silicate rocks are mineralogically and texturally identical with those in the closely associated silicate rocks. Those in the carbonate-silicate rocks clearly have not been formed by the recrystallization of minerals previously granulated, and it is therefore concluded that those in the silicate rocks have not had such an origin.

The genetic relation between the carbonate and noncarbonate rocks thus implied was clarified by large-scale mapping near Kings Mountain. There, the quartzite occurs interbedded with west-dipping rocks of the other types but is most abundant in two distinct zones within the limestone. The upper or western limit of the limestone throughout the area is about equidistant from the irregular eastern margin of a large granitic body and occurs at some places above the upper quartzite zone and at other places below it. The carbonate-silicate rocks, largely equivalent to the Blacksburg schist, have been found throughout the limestone as sporadic layers and bodies of indefinite outline, but they are most abundant near the irregular upper limit of the limestone—the lower limit of conformably overlying hornblende gneiss sharply interlayered with mica schist.

The upper quartzite is thus in a zone of transition from carbonate to silicate rocks, and the relation of this zone to the margin of the granite indicates that the transition is of metamorphic origin. The layers of hornblende gneiss immediately above the limestone are strongly metamorphosed beds of the limestone series, but it is not known whether they originally contained all the elements necessary to form the silicate minerals. Evidence for the chemical transfer of material is the presence of hornblende, tremolite, and microcline porphyroblasts in the limestone and of tourmaline, albite, microcline, and spodumene in the silicate rocks only near pegmatite and granite. It is believed that the granite was the source of aqueous solutions that invaded the sedimentary rocks and effected their recrystallization or reconstitution. The granite is apparently of late Carboniferous age; the country rocks are older, but no evidence could be found for determining their actual age.

Thus, near Kings Mountain, mica schists and gneisses previously mapped as Carolina gneiss, and hornblende gneisses previously mapped as Roan gneiss, actually constitute the metamorphosed upper part of the Gaffney. Similar rocks in the Beaverdam Creek area apparently are stratigraphically higher. The micaceous rocks were derived by the metamorphism of shaly rocks, and the hornblendic rocks by the metamorphism of pure or impure calcareous rocks, regardless of the stratigraphic position of either type. Evidence in other parts of the Carolina Piedmont, according to the literature as well as reconnaissance observations by the writer, indicates that intrusive diorite and possibly recrystallized mafic volcanic rocks have been included in the Roan, and possibly recrystallized felsic volcanic rocks in the Carolina. The names Carolina and Roan, therefore, have lithologic but not stratigraphic significance, and the rocks associated with them probably will be divided eventually into formations on the basis of comparative genetic history rather than physical appearance.

INTRODUCTION

In a recent report by the writer (1942) on the occurrence of cassiterite and spodumene in albitic pegmatite in the Carolinas, geologic details having no economic bearing were of necessity minimized. The most significant findings involve the origin and correlation of the country rocks adjacent to the pegmatites. In this respect the results differ quite markedly from those of Keith (1931; also incomplete manuscript geologic map of the Lincolnton quadrangle, N. C.), who, with Sterrett, had mapped the geology of most of the belt on a scale of 1:62,500. Also, the interpretation of the origin of the pegmatite, and of the paragenesis of its minerals, as outlined in the report cited above, differs from those of Graton (1906, p. 20–22, 36–37, 42–44) and Hess (1940, p. 951–952, 956–957). The more detailed study by the writer and, to some extent, changes in general interpretation probably account for these differences.

The present paper supplements the economic report. The field work included plane-table mapping on scales ranging from 10 to 250 feet to the inch, and the careful examination of 2443 outcrops, in six areas within the pegmatite belt. These areas contain 839 exposed pegmatite bodies a foot or more thick and abundant smaller bodies, as well as country rocks of nearly every type exposed in the belt. The remainder of the belt was examined but was not mapped. Laboratory work included a study of 124 thin sections cut from rocks of all varieties, including 61 from the country rocks, as well as the identification of many feldspars and other minerals in immersion media.

The painstaking assistance of P. M. LeBaron, R. A. Edwards, R. M. Barbour, H. E. LeGrand, and J. C. Morris in the field is gratefully acknowledged. The manuscript has been critically read by G. F. Loughlin and C. S. Ross whose comments and suggestions have been most helpful.

GEOLOGIC SETTING

GENERAL STATEMENT

The area studied (Fig. 1) is a strip of the Carolinas 36.5 miles long and 1.8 miles in maximum width. Because of its shape and the presence of cassiterite deposits, it has long been referred to as the Carolina tin belt; because of the current development of the spodumene, the term tin-spodumene belt has been used. Both the belt and the adjacent region are underlain by crystalline rocks of somewhat wider range in composition than is characteristic of most of the Piedmont province. The variety of mineral deposits is also more diverse, but most of the deposits are of marginal grade under normal economic conditions. The cassiterite and spodumene occur in and associated with albitic pegmatite bodies which occur in large numbers from the northeast end to the vicinity of Grover. A single deposit of cassiterite occurs in South Carolina, near Gaffney, in pegmatite that contains no spodumene.

The rocks of the belt as a whole are divided by their physical relations into three major groups of which only the youngest and least abundant can be dated with confidence. In the order of decreasing age, these major groups are the metamorphic country rocks, the granitic rocks and pegmatite, and Triassic diabase.

COUNTRY ROCKS

The country rocks comprise mica schists and gneisses which contain, in places, graphite and secondary quartz, staurolite, and opaque ore minerals; hornblende, hornblende-biotite, and rare pyroxene gneisses; crystalline limestone and dolomite, much of which is micaceous; quartzite; and a few small bodies of coarse-grained "soapstone" and deeply weathered chloritic rocks. Similar rocks underlie the surrounding region together with partly altered volcanic rocks, meta-conglomerate, and mica schists largely replaced by quartz and kyanite (the kyanitic varieties of Keith's Kings Mountain quartzite and Carolina gneiss). These rocks commonly occur in sharply defined layers whose internal foliation or mineral alinement is essentially parallel to the planes of separation between the layers. The maximum local deviation observed is 14 degrees. In the belt studied, the layers and foliation strike

generally northeast and dip steeply northwest except in the vicinity of Gaffney, where they dip southeast. Graton (1906, p. 30–31) regarded all these rocks as of pre-Cambrian age, but Keith (1931) divided them into Archean, Algonkian, and Cambrian formations on the basis of lithologic resemblance to rocks mapped similarly

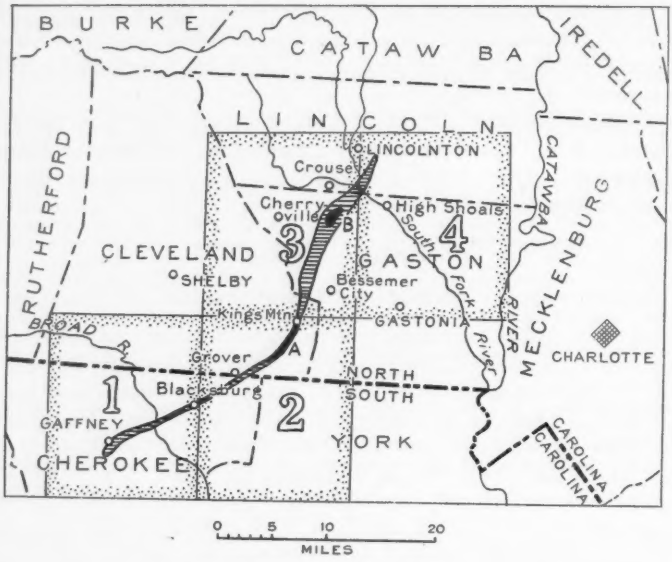


FIGURE 1.—*Index map*

Showing location of area studied, in relation to 15-minute quadrangles. The quadrangles are: 1, Gaffney; 2, Kings Mountain; 3, Lincolnton; 4, Gastonia. Parts of the area shown in black: A, Kings Mountain area (Pl. 1); B, Beaverdam Creek area (Pl. 3).

in other parts of the Southern Appalachians. Most of Keith's formations contain rocks of such diverse specific composition that they are not amenable to large-scale plane-table mapping.

No certain criteria are known to determine the actual age of the country rocks. In general, the ages assigned by Keith are intended to express the amount of textural and mineralogic change imposed by metamorphism, with the more coarse-grained foliated rocks considered to be the older. Such an age assignment implies that rocks of the same age had the same original lithologic character everywhere and then were metamorphosed identically. Aside from the fact that this would be an extremely fortuitous circumstance, there is no allowance for the vertical and horizontal variations in metamorphic effects to be expected in an environment where granitic magma and magmatic emanations have permeated to different degrees in different places over a very large region.

The results of the present work indicate that the separation of the rocks of the belt into pre-Cambrian and Cambrian formations is not justified. At least parts of Keith's

Carolina and Roan (pre-Cambrian) formations in the area studied are metamorphosed parts of his Gaffney (Cambrian) formation as described below. The consequent effect on stratigraphic correlations is of regional importance in view of the continuity of these rocks beyond the limits of the belt.

GRANITIC ROCKS AND PEGMATITE

Granitic rocks, consisting largely of potash and soda feldspars, quartz, and micas, are abundant, and all are younger than the metamorphic country rocks. Some of the contacts are sharp and clearly intrusive, whereas others are just as clearly gradational and might be termed pervasive to imply the combined results of metasomatic replacement and the crystallization of new minerals in minor openings formed mechanically. Pegmatite is abundant in places; in the area with which this paper deals it is highly albitic and intergrades with Keith's Whiteside granite. The contacts between pegmatite and country rocks are sharp in some places and gradational in others.

The structure of the granitic rocks and pegmatite ranges from nonfoliated to highly foliated. This is commonly true of single bodies, particularly among the granitic rocks whose mineral composition also is not nearly so uniform as the meager published descriptions would indicate. Graton (1906, p. 31, 44) considered all the granitic rocks and pegmatite to be pre-Cambrian. Keith (1931, p. 4, 6) regarded the strongly foliated types as pre-Cambian and the weakly foliated and nonfoliated types as probably late Carboniferous; no sharp line of separation was drawn, nor can it be, owing to the range of intensity of the foliation within single bodies. The wide range and intergradation of foliated structure indicate that Graton correctly regarded all the granitic rocks and pegmatite as of the same general age.

Both Graton and Keith adhered to the assumption, still commonly held, that the foliation of large parts of the granitic and pegmatitic rocks was developed by the deformation of nonfoliated rock—hence, Keith's division of the granitic rocks into pre-Cambrian and Carboniferous groups. There appears, however, to be little if any relation between the intensity of foliation of these rocks and cataclastic modification of their constituent mineral grains. This and other reasons suggest to the writer that the strongly foliated rocks loosely termed granitic gneisses are the products of pervasion of fine-grained mica schist, which is abundant in the region, by magmatic emanations from the crystallizing granite.

The nature of the investigation did not permit a careful study of this problem, but the origin suggested would account for the complex intergradation of foliated and nonfoliated granitic rocks. It would reverse their age relations, however, by making the origin of the foliated types dependent on relative proximity to the nonfoliated type which is accepted by Southern Appalachian geologists as Carboniferous.

DIABASE

Dikes of unmetamorphosed diabase cut all other rocks in the region. They are similar to dikes that cut rocks of the Newark (Triassic) group in the Dan River coal field (Stone, 1912, p. 144–145) to the northeast and both Newark rocks and under-

lying schists in the Deep River coal field (Campbell and Kimball, 1923, p. 45–49) to the east. Keith (1931, p. 7) regarded the dikes in the area described in this paper as of the same age, and the correlation appears to be well justified.

The dikes are thin, steeply dipping, tabular bodies that range in thickness from an inch or less to 35 feet. Most of them trend N. 40°–50° W., approximately at right angles to the regional strike, but a few of the thinner dikes trend parallel to the layers of the country rocks.

Where pegmatite occupies joints, three sets of the joints parallel the predominant strike of the diabase dikes; one of the dikes contains an inclusion of pegmatite. Some of the joints in which diabase was emplaced, therefore, may be prepegmatite in origin. The diabase dikes traced consist of relatively short bodies roughly alined so that they appear to form long, continuous bodies as mapped by Keith and Sterrett (1931, areal geologic map).

PHYSIOGRAPHY AND WEATHERING

The area studied is a part of the Piedmont province, a moderately dissected plateau that slopes very gently eastward. The altitude of the adjacent upland surface is 800 to 1000 feet. The principal streams in this part of the plateau are the South Fork and Broad rivers, whose channels have been cut 200 to 300 feet below the upland surface. Their tributaries have dendritic patterns except locally where trellis patterns have been formed by the differential erosion of quartzite, highly siliceous mica schists, and carbonate or carbonate-bearing rocks. Slopes from the divides to the streams are rather gentle; steep slopes and bluffs occur only at wide intervals along the principal streams and on a few monadnock peaks and ridges that rise 200 to 700 feet above the plateau.

Most of the land is cultivated although the soil cover rarely exceeds 2 feet and is less than a foot thick in many places. Rocky areas, underlain mostly by siliceous schists, quartzite, and quartzose pegmatite, are wooded. Bedrock beneath the thin soil has been thoroughly weathered to an uneven depth that exceeds 50 feet in places and is greatest on the broad divides that form the plateau level. The deeply weathered rock has been termed saprolite by Becker (1895, p. 289, 290); the term specifically implies rotten, untransported rock that retains the structural and textural characteristics of the fresh rock, but few of the original minerals. The saprolite presents both difficulties and advantages in geologic mapping. The principal difficulty arises from the tendency of fine- to medium-grained feldspathic gneisses of different mineral composition, which commonly look similar when fresh, to weather to saprolites that look even more similar. Rocks of more distinctive appearance where fresh, such as the highly mafic gneisses, extremely quartzose rocks, coarse-grained granitic rocks, and muscovite and biotite schists, weather to saprolites that are also distinctive. The residuum of crystalline limestone and dolomite is easily recognizable, but the less pure carbonate rocks, containing the silicate minerals described below, weather to saprolites that can be recognized only after considerable experience with them, and even then not with certainty regarding all the original minerals.

The greater part of the problem of identifying the original rocks represented by

the different saprolites was solved by finding exposures in which the saprolites graded into the respective rocks from which they were derived. Parent rocks sufficiently fresh for petrographic work were found for every type of saprolite in the belt except that derived from the rare chlorite rocks.

This procedure was essential in detailed geologic mapping, for rocks of widely different mineral composition are here closely interbedded and interlayered. Since the number of exposures of saprolitic rocks far exceeds that of fresh and semi-weathered rocks, the identification of most of the saprolites greatly enlarged the possibilities of large-scale mapping. It did not, however, permit the mapping of contacts between individual layers of the metamorphic rocks through relatively broad areas in which the saprolites are covered by soil. Even where the soil clearly has been formed with but slight transportation of material, the rock fragments that occur as float are derived from the most resistant but not necessarily the most abundant variety of rock beneath.

Foliation so weak as to be scarcely discernible in thickly layered fresh rock is emphasized by weathering and therefore could be determined with little difficulty, if necessary from sizable blocks cut from the outcrops. A very good impression of the proportion of quartz to feldspar in fine-grained feldspathic gneisses was obtained in the field from saprolitic outcrops. Equally good impressions of the relative proportions of microcline to plagioclase were obtained from weathered gneisses of coarser grain. It was found also that weathering emphasizes the presence of small amounts of ferromagnesian minerals and of graphite which might not be recognized in the fine-grained fresh rocks.

DESCRIPTION OF THE COUNTRY ROCKS

GENERAL DESCRIPTION

In a preliminary reconnaissance of the belt, two areas were recognized in which nearly all types of country rocks are best exposed. The full range of structural features of both country rocks and pegmatite is also well exposed. These areas were mapped on a scale of 250 feet to the inch. One area extends southwest for 4.2 miles from the southern limit of the town of Kings Mountain; it is referred to herein as the Kings Mountain area (Pl. 1). The other, 2.2 miles in length, is on Beaverdam and Little Beaverdam creeks 6 miles south-southwest of Lincolnton and is referred to as the Beaverdam Creek area (Pl. 3).

The stratigraphic relations of the country rocks cannot be discussed adequately without first describing the rocks, particularly as they occur in these two areas. Owing to the scarcity of petrographic descriptions of these rocks, and of similar rocks in the adjacent region, the descriptions that follow are as full as the scope of the investigation permits; they are necessarily so because the genetic relations of the rocks are shown, in part, by the similarity of their constituent minerals. The country rocks other than quartzite, carbonate rocks, and carbonate-silicate rocks are referred to collectively as silicate rocks.

The paragenesis of only a few of the minerals is clear, and inferences based on the relations of these minerals are purposely limited to avoid broad speculation. The

marked changes, within short distances, of the proportions of the rock-forming minerals make it unlikely that chemical analyses of the rocks would throw additional light on the problems studied. Minerals of the silicate rocks, such as augite, garnet, staurolite, and enstatite, which are supposedly formed at relatively high temperature, occur irregularly with the lower-temperature minerals and are in no sense restricted to zones. Minerals of restricted occurrence include tourmaline, albite, microcline, spodumene, and probably rutile which are present only near pegmatite or granite.

QUARTZITE

Thin, lenticular beds of quartzite are common in the Kings Mountain area but are most abundant in two stratigraphic zones, Q1 and Q2 (Pl. 1). The beds are sharply defined, and they alternate with equally well defined beds of the other country rocks. The sharp definition of the beds distinguishes the quartzite from highly siliceous schists common east of the belt. The rock consists of fine-grained anhedral quartz and shows no detrital grains. Some beds contain a little fine-grained muscovite oriented parallel to the bedding.

Fine-grained subhedral tourmaline occurs in and strictly parallel to many of the bedding planes in the quartzite of zone Q2; it is not generally disseminated in the rock. The tourmaline appears greenish black under the hand lens, but the pleochroic colors parallel to *Z* are light brownish green and pale greenish blue; if present, the blue color is limited to the interior of a crystal and reveals irregular and poorly defined zoning. The origin of the tourmaline is not clear, but similar tourmaline was abundantly introduced into other rocks in the belt, particularly mica schist, and the tourmaline in the quartzite may have been introduced along the few bedding planes in the same manner as along the many planes in the schist.

Most of the quartzite of zone Q1 is finer-grained than that of zone Q2. It contains, in places, much intermixed, fine-grained muscovite and greenish-brown biotite whose crystals lie characteristically along the grain boundaries of the quartz and appear to have crystallized after the quartz. The micas thus have diverse orientation throughout most of the rock but parallel the bedding in a few laminae where quartz is subordinate or absent. The quartzite also contains, in places, much fine-grained magnetite, disseminated and in random, thin aggregates in the bedding planes.

The two quartzite zones in the Kings Mountain area also differ markedly in thickness. Zone Q1 has a thickness of 50 feet or more along the entire southeast margin of the area although mapping was not extended far enough in this direction to include the entire zone. Its beds are thicker, more persistent, and are separated by fewer beds of other rocks than are those of zone Q2. The beds present in zone Q2 are quite variable in number and thickness within short distances. The maximum thickness of massive quartzite is 15 feet in two exposures, but the zone in most places consists of only a few beds, each less than a foot thick, separated by conformable beds of other rocks.

The two zones crop out about the same distance apart through the entire Kings Mountain area (Pl. 1), although in the same area Keith divided zone Q1 structurally into different parts and showed zone Q2 to be present only at the extreme northeast and southwest ends (Fig. 2). Aside from these marked differences regarding pres-

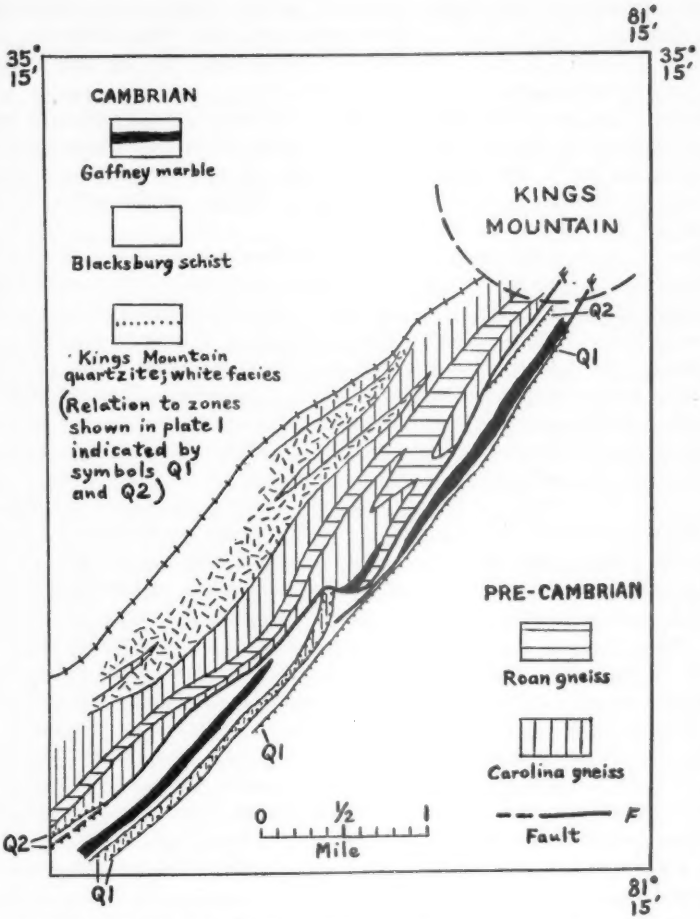


FIGURE 2.—*Geology of the Kings Mountain area (Pl. 1) as mapped by Arthur Keith*

ence and continuity of the quartzite, the two zones were regarded by Keith (1931, areal geologic map and structure sections) as the same stratigraphic unit repeated by folding and faulting. The two zones are dissimilar in every major respect, and probably they are separate units; their status will be further considered in the discussion of age relations of the country rocks.

CARBONATE ROCKS

Keith and Sterrett (1931, areal geologic map; also incomplete manuscript geologic maps of the Lincolnton and Hickory quadrangles, N. C.) have mapped a nearly continuous series of well-bedded crystalline limestone and dolomite from Gaffney,

S. C., northeastward into eastern Cleveland, western Gaston, and eastern Lincoln and Catawba counties, N. C. These carbonate rocks, which comprise Keith's Gaffney marble (1931, p. 6), crop out at intervals along the east side of the belt discussed in this paper.

In the Kings Mountain area, the carbonate rocks occur mostly between the two zones of quartzite and have weathered more readily than the other rocks, forming strike valleys such as that of Mill Creek. Fresh rock is exposed only in the channels of the larger streams, in large active quarries at Gaffney and Kings Mountain, and in smaller quarries now abandoned.

Some of the beds consist only of fine- to medium-grained calcite and dolomite in quite variable proportions, but quartz, apparently introduced during metamorphism, is a common impurity. Analyses of the relatively pure carbonate rocks near Gaffney, given by Sloan (1908, p. 257–261), show a range of 54.39 to 96.86 per cent calcium carbonate, and 1.33 to 39.98 per cent magnesium carbonate. The crystals are anhedral and are of approximately equal size in a single bed. They are irregular to roughly equidimensional in shape; elongate grains are rare. Lamellar twinning is common, but the lamellae are broad and widely spaced. The rocks apparently have not been greatly deformed since they recrystallized, for marbles showing about the same amount of twinning as these carbonate rocks developed thinner and much more closely spaced lamellae under confining pressures in the experiments of Adams and Nicolson (1901, p. 393, 400, Pl. 24) and of Griggs (1936, p. 567–568, Pl. 5).

Many beds of the carbonate rocks are schistose owing to the presence of fine-grained muscovite, phlogopite, and chlorite; graphite is common in these beds. The micaceous rock appears to have recrystallized from the originally argillaceous parts of the series. Magnesia essential for the formation of the phlogopite and chlorite is assumed to have been derived from the dolomite, but no exposure could be found sufficiently continuous along the strike to show a clear relation of either mineral to beds of magnesian rock. In this connection, considerable difficulty was encountered in differentiating some of the fine-grained micas of both the carbonate and carbonate-silicate rocks. In general, the indices of refraction, pleochroism, and axial angles distinguish muscovite, phlogopite, and biotite with reasonable certainty, but pleochroism is particularly variable and probably reflects slight variations in composition.

CARBONATE-SILICATE ROCKS

The origin of the carbonate-silicate rocks is the most important problem in petrogenesis in the belt, but these rocks are the most poorly exposed. They occur in all parts of the carbonate rocks in the Kings Mountain area but are most abundant in a transitional zone between the carbonate rocks and the silicate rocks to be described. The carbonate-silicate rocks contain, intermixed, the minerals that characterize both the carbonate and the silicate rocks, although they are clearly impure parts of the carbonate rocks.

The carbonate-silicate rocks have a wide range in composition. Like the carbonate rocks, they contain calcite and dolomite, and commonly muscovite, phlogopite, chlorite, and quartz, but are distinguished from the carbonate rocks by the presence

of one or more of the following silicate minerals, listed in the approximate order of decreasing abundance: hornblende, biotite, plagioclase, epidote, tremolite, sphene, zircon, and microcline.

The carbonate is leached rapidly during weathering so that the rock structure collapses, leaving no easily recognized saprolite. These rocks can, therefore, be identified with certainty only if fresh or nearly so, and their importance has been overlooked owing to the scarcity of fresh exposures.

Some of the carbonate-silicate rocks are rather sharply interlayered with the limestones, schists, and gneisses, but the continuity of individual layers along the strike could not be determined because of the limited linear extent of the outcrops. Other rocks of this type occur as irregular or lenticular bodies in beds of the carbonate rocks. In some beds these bodies are only a few inches or a few feet in greatest dimension and grade into the enclosing carbonate rock.

As previously stated, muscovite, phlogopite, and chlorite in the carbonate rocks were probably recrystallized from argillaceous constituents. It could be reasoned that other silicate minerals in the carbonate-silicate rocks are likewise the products of recrystallized impurities. This inference is plausible for the rather sharply defined beds of the carbonate-silicate rocks, but it does not account for the small, highly irregular bodies that occur sporadically in limestone beds. It also does not account for the relatively large crystals of silicate minerals developed in limestone that does not and apparently never did contain the chemical constituents necessary for their growth. A few examples will illustrate the wide range in the mineral composition of these rocks, a succession in time of development of some minerals present in the same rock, and the occurrence of some of the silicate minerals in environments that could not have supplied the material necessary for their development. These examples are numbered below and the locations of the first four are shown in Plate 1.

(1) At locality number 1, which now is within the limits of the quarry of the Superior Stone Company, a layer of carbonate-silicate rock was found in the limestone exposed in a steam channel. The rock is fine-grained, schistose, and greenish brown. Deep-brown biotite and light-bluish-green amphibole, in about equal amounts, are the most abundant minerals in the rock. The biotite is strongly oriented, giving the rock its foliation, and is mostly confined to thin layers which alternate with nearly biotite-free layers. Hornblende, in contrast, is present throughout the rock and is less strongly oriented; it shows no genetic relation to the biotite. The matrix consists of a little quartz and much fine-grained, untwinned plagioclase which has corroded the hornblende but not the biotite. The plagioclase is anhedral, and the rims of many grains show higher indices of refraction than do the cores. The actual indices, as determined in immersion media, indicate an outward change in composition from calcic oligoclase to sodic andesine. Zoning of plagioclase is uncommon in the metamorphic rocks of this region. A little interstitial calcite is present, but it shows no good evidence of having been replaced; it is interpreted as residual calcite that recrystallized as conditions favorable to the development of the other minerals ended. The rock also contains a very little widely disseminated sphene and epidote. The sphene is rather closely associated with a fine-grained opaque mineral, possibly ilmenite.

Three characteristic features of the principal minerals that suggest paragenetic relations are: (1) corrosion of hornblende, but not of biotite, by plagioclase; (2) the lime-rich outer zones of the plagioclase; and (3) the occurrence of biotite mostly in thin layers in which the relations of hornblende and plagioclase are the same as elsewhere.

The hornblende was developed first and was then corroded by the solution from which the plagioclase developed. Thus, the solution would have been slightly enriched with lime, with a corresponding increase in the lime content of the crystallizing plagioclase.

The restriction of the biotite to thin laminae in the rock suggests the original presence of aluminous layers. The aluminous layers in the quartzite zones and in the carbonate rock series were originally shales recrystallized to muscovite schist. The biotitic, or aluminous, layers in this rock, therefore, may originally have been shaly layers, and the mica may have been muscovite prior to the corrosion of the hornblende. If so, the muscovite could have recrystallized to biotite with the addition of magnesia and iron from the hornblende, and by the loss of alumina to the plagioclase.

Although based on inference, as the composition of the recrystallizing solution is not known, this explanation would account for the apparently contemporaneous origin of plagioclase and biotite after hornblende and would also account for the potash in the biotite. It is entirely possible that potash was introduced into the rock, but the restricted occurrence of the biotite and the unrestricted occurrence of hornblende and plagioclase do not support this view. The absence of potash feldspar may also indicate that no appreciable amount of potash was supplied from the outside, for potash feldspar is present in other country rocks only near granite and pegmatite.

(2) A thin layer of dull-green rock, somewhat less schistose than type (1), occurs 800 feet southwest of the quarry, interbedded with limestone in the bed of Mill Creek. It consists largely of fine-grained, rarely twinned, anhedral plagioclase (An_{27}) and hornblende similar to that in type (1). The hornblende in type (2) also appears to have been corroded by the plagioclase, but the plagioclase is not zoned; fine-grained epidote, generally disseminated, appears to be a reaction product of the corrosion. Biotite was developed, as in type (1), but most of it was altered further to chlorite, and only scant remnants of it remain. Quartz is intermixed with the plagioclase. Calcite occurs mostly in irregular aggregates of comparatively coarse grains but is also distributed throughout the rock as small interstitial grains. The rock contains abundant subhedral to euhedral pyrite which is associated principally with the calcite. A much less abundant and finer-grained opaque mineral is associated with the epidote.

(3) A layer of rock possibly several feet thick, and similar in appearance to the two varieties just described, crops out in the channel of a tributary of Mill Creek, 1.2 miles southwest of the quarry. Like type (1), and unlike type (2), the rock contains abundant unaltered brown biotite, but unlike both it contains no amphibole. The biotite is well oriented parallel to the bedding and is rather evenly distributed in a matrix of anhedral, untwinned plagioclase (An_{28}) and quartz. Relatively coarse-

grained calcite is present in irregular aggregates and as sparse interstitial grains. Fine-grained, subhedral to euhedral sphene and anhedral epidote are distributed evenly through the rock, and coarser-grained pyrrhotite is distributed less evenly.

(4) Light-gray, slightly muscovitic limestone, 600 feet northwest of the outcrop of rock type (3), contains aggregates of tremolite crystals intermixed with calcite and a little residual muscovite. The limestone effervesces vigorously without being powdered and apparently is very low in magnesia. The tremolite occurs in crystals as much as 0.5 inch in length oriented diversely, and some are grouped in radiating clusters. The tremolite is colorless and nonpleochroic. $Z \wedge c = 16°$, and the birefringence is about 0.027. The tremolite obviously has replaced the limestone, yet the calcite of the rock permeates slight fractures in the tremolite and, therefore, must have crystallized after the development of the tremolite.

This seemingly contradictory evidence, which also applies to each variety of the carbonate-silicate rocks studied in detail, evidently means that the silicate replaced the limestone but not the calcite in its present crystal form. The tremolite appears to have developed, by the addition of silica, within the span of time represented by the solution and subsequent crystallization of the calcite. Finer-grained calcite also clouds the interiors of the tremolite crystals, giving them a poikilitic texture. In view of the possibly post-tremolite crystallization of the calcite matrix, these inclusions also may have crystallized late as excess carbonate resulting from a lack of sufficient silica to form complete tremolite crystals.

(5) The largest quarry in the carbonate rocks of the belt is near Limestone College at Gaffney. Muscovite, phlogopite, quartz, and chlorite are common impurities in the rocks here, but most of the beds are pure enough for commercial uses. The quartz is very unevenly distributed and shows no alinement parallel to bedding in thin section. Its boundaries with calcite and dolomite are characteristically rounded and convex. Aggregates of quartz grains contain many residual areas of the carbonates, and the aggregates have no definite outlines. Quartz veinlets cut the carbonate rocks; the grains in the veinlets are similar to the random grains in the rock; also, the quartz grains along the margins of the veinlets show the same contact relations with the carbonate minerals as do the disseminated grains. The disseminated quartz therefore appears to be secondary rather than detrital.

Thin, dark, micaceous beds in the limestone, exposed in 1940 on the south rim of the quarry, contain veinlets of fine-grained quartz, sporadic porphyroblasts of microcline, and unevenly disseminated pyrite. The enclosing rock consists of calcite, quartz, deep reddish-brown to brownish-green biotite, and a very little muscovite and epidote. The microcline crystals occur singly and in small groups. Most of them are 0.1 to 0.3 inch in maximum dimension, whereas calcite, the coarsest mineral in the enclosing rock, occurs but rarely in crystals as thick as 0.05 inch. The microcline contains a few included grains and aggregates of the biotite, calcite, and muscovite that characterize the enclosing rock. The porphyroblasts are also moderately fractured and veined by the calcite, as is true of the tremolite of type (4), suggesting that the microcline developed before the final crystallization of the carbonate. The rock contains no apparent source of materials necessary for the development of microcline except the micas. Muscovite is too sparse to be a possible source, and

neither muscovite nor biotite shows any alteration or any distributional relation to microcline.

(6) An old quarry known as the Finger is located 4.5 miles east-northeast of Lincolnton, in strike with the carbonate rocks near Kings Mountain and Gaffney. Some of the rock quarried here was burned for lime in a kiln, the ruins of which still remain. The quarry reportedly has been abandoned since about 1880, and the bottom and sides have been covered with erosional debris. Little waste rock was left, and most of it is carbonate-silicate. One variety is a dark, grayish-brown, fine-grained rock that contains hornblende porphyroblasts up to 0.7 inch long, abundantly disseminated pyrrhotite, and veinlets of fine-grained calcite most of which parallel the sharply-defined bedding. Pyrrhotite veins the hornblende, is therefore later, and could not have furnished iron for the development of the hornblende. The c axes of the individual hornblende crystals are oriented in different directions, but, where the crystals are grouped, the groups are arranged mostly along the bedding. The optical properties of the hornblende are as follows: $Z \wedge c = 24°$; birefringence 0.02 (α 1.638, γ 1.658); r > v; $2V$ (−) moderate; Z light bluish green > X and Y pale yellowish green.

In thin section, calcite is the most abundant mineral; it is generally disseminated through the rock and also occurs in veinlets. Where interstitial, it is finer-grained and has more ragged outlines than in the veinlets. Light-brown biotite, having an index of 1.61 in sections parallel to the cleavage, is next in abundance and gives the rock its brown hue. The biotite has jagged boundaries but is unaltered; it occurs with the disseminated calcite. Smaller crystals of the same hornblende that occurs as large megascopic crystals occur sporadically in the matrix of calcite and biotite and show no relations that indicate genetic sequence. The hornblende is unaltered, but the crystals are extremely irregular and contain many inclusions of calcite, as does the tremolite in type (4) of the carbonate-silicate rocks. The calcite in places is so abundant that the hornblende crystals consist of unjoined segments that extinguish together. This texture is interpreted as coarsely poikilitic owing to the obvious late development of the larger crystals. Less abundant minerals include, besides pyrrhotite, a little quartz, sphene in greater abundance than in any other carbonate-silicate rock studied, clinozoisite, rutile (associated possibly with a little ilmenite), and apatite.

MICA SCHISTS AND GNEISSES

Fine- to medium-grained rocks that contain large amounts of micas are abundant in the belt and adjacent region and are interlayered with all other types of rocks. The schists consist predominantly of muscovite with very small amounts of granular and prismatic minerals. The gneisses, finer-grained and more micaceous than the granitic gneisses discussed above, are characterized by muscovite or biotite or both but contain equal or greater amounts of anhedral feldspar or quartz or both. With increase or decrease in the abundance of these granular minerals, the schists and gneisses intergrade commonly along the strike and much less commonly across the strike. Subordinate minerals that occur irregularly in the schists and gneisses include

chlorite, garnet, epidote, apatite, staurolite, tourmaline, rutile, zircon, pyrite, pyrrhotite, and ilmenite. Andalusite has been found as float associated with these rocks, but its identity as a constituent could not be established.

The micaceous minerals are usually but not invariably oriented parallel to the layers of the rocks. All are fine-grained, although a slightly coarser grain size is apparent near exposed granite. In thin sections of the gneisses, the micas are not commonly segregated in layers but are well distributed among the granular minerals. The quartz and feldspar grains are anhedral, contain practically no inclusions, and rarely show even mild effects of physical disturbance. The feldspar is plagioclase; in mica gneisses from 11 localities its composition has a range of An_{10} to An_{40}, with An_{23} dominant. Twinning is scarce, and cleavage shows poorly.

Near some contacts with granite and pegmatite, these rocks contain either microcline or albite (α1.525), and near a few contacts both are present. In the schists, these minerals occur sporadically as porphyroblasts of megascopic size. In the gneisses, the microcline occurs as microcline-myrmekite which embays the plagioclase; the presence of albite was determined in immersion media, but the mode of occurrence has not been studied. Spodumene is a rare constituent of coarsely recrystallized schist near contacts with pegmatite. The microcline and albite of these occurrences were clearly introduced by solutions emanating from the adjacent granite and pegmatite, and the spodumene from pegmatite only.

The subordinate minerals merit brief discussion. Chlorite has about the same grain size as the micas, and its occurrence is similar to that of the micas. It commonly accompanies muscovite regardless of the presence or absence of biotite and garnet. It rarely occurs as a definite alteration product of biotite, shows no relation to garnet, and the relative abundance of the three minerals is not consistent.

Most of the garnet is fine-grained, subhedral to euhedral, rarely cracked, and almost nowhere altered hydrothermally. It contains no inclusions. Crystals coarse enough for color to be evident are red to reddish brown. Weathering of the garnet develops strong iron-oxide stains in which manganese oxide is not apparent. The refractive index of the garnet in a typical rock of this group was determined as 1.82. This, together with the iron-oxide stains, indicates a dominance of the almandite molecule.

Anhedral to euhedral epidote, apatite, and zircon occur at random. Staurolite occurs similarly in a few places where it is relatively abundant. Tourmaline is found only near pegmatite, and rutile, much scarcer than tourmaline, also seems to occur near pegmatite as well as granite. Largely anhedral pyrite, pyrrhotite, and ilmenite are very irregularly disseminated.

Much of the muscovite schist is interbedded with quartzite and crystalline limestone, indicating that most or all the schist is recrystallized shale. It is not known, however, whether the principal minerals of the mica gneisses, exclusive of muscovite, crystallized from originally impure shales or from materials introduced during the metamorphism of shale; sufficient information has been gathered to indicate that either origin is possible. Crystallization was uninterrupted, probably marked at the close by the formation of the chlorite, and all minerals remained stable throughout the process.

HORNBLENDE AND HORNBLENDE-BIOTITE GNEISSES

These fine- to coarse-grained rocks contain hornblende and/or biotite. Rocks containing biotite only are not abundant and are distinguished from the biotitic rocks of the micaceous group by their more calcic plagioclase and by their intergradation with the rocks that contain hornblende. Hornblendic rocks without biotite are very common.

These rocks contain hornblende, biotite, plagioclase, quartz, and accessory epidote, sphene, apatite, one or more opaque minerals, and rare chlorite and augite. These minerals, even the principal ones, are rarely all present together, and the range of their proportions is bewildering. Owing to differences in the amounts of hornblende, the rocks that contain little or no biotite range from greenish black to light, speckled, greenish gray. Brown tones are imparted by biotite. The proportions of plagioclase and quartz are equally variable, but are much more difficult to determine because much of the plagioclase shows no twinning and few cleavage planes and has indices of refraction very close to those of quartz. The subordinate minerals are as variable in amount as are the principal minerals.

The hornblende has the same general optical properties as that in the hornblendic carbonate-silicate rocks. $Z \wedge c$ = about 19°; the maximum index of refraction ranges from 1.64 to 1.69, but is most commonly about 1.67; the birefringence ranges from 0.015 to 0.025. X and Y are colorless to light yellowish or brownish green; Z ranges from brownish green to bluish green and is in general bluish. There is every conceivable gradation of color between the extremes of color parallel to Z and likewise all gradations from pale to deep shades.

In a single specimen the hornblende is usually uniform in color and optical properties, but two thin sections cut from rocks in the Beaverdam Creek area contain light brownish-green crystals extensively blotched deep greenish-blue, especially in their outer parts. The crystals are optically uniform regardless of the variations in color. In contrast to the normal, unblotched hornblendes, in the blotched variety $Z \wedge c$ = 25°. Gilluly (1933, p. 69, 74) has described a somewhat similar amphibole whose origin he attributed to attack of sodic solutions on ordinary green hornblende. The same explanation seems applicable here; the rocks occur within 100 feet of pegmatites whose principal constituent is albite. The hornblendic rocks near by contain albite rarely, and only near pegmatite.

An even more convincing example of the introduction of both soda and potash into hornblende gneiss was found in the Beaverdam Creek area. The gneiss on either side of a joint, which cuts nearly at 90° across the foliation, has a bleached, light-colored appearance which diminishes in intensity away from the joint. The light-colored rock contains much albite and microcline, neither of which occurs in the rock of normal appearance.

The composition of the plagioclase in the hornblende and hornblende-biotite gneisses from 13 localities ranges from An_{23} to An_{42}; the calcic end of the range is dominant. An unusual variety of the hornblende gneiss, in the Kings Mountain area, contains a few crystals of bytownite (An_{83}) enclosed in later labradorite (An_{65}). Plagioclase in all these gneisses is anhedral to subhedral. The anhedral crystals commonly show little or no twinning and are arranged in semimosaic texture with or

without quartz. The subhedral crystals are short laths invariably twinned and are less commonly intercrystallized with quartz. Anhedral and lath-shaped crystals rarely occur together.

Most of the hornblende of these rocks occurs in irregular crystals embayed, as though corroded, by the plagioclase. The biotite, which is brown to greenish brown and has a refractive index of 1.625 to 1.648 in sections parallel to the cleavage, shows no direct genetic relation to the hornblende. The relations and possible paragenesis of the three minerals are similar to those described for types (1) and (2) of the carbonate-silicate rocks, but the plagioclase is rarely zoned, and excess lime from the hornblende appears to have entered mostly into the development of epidote.

Accessory epidote, sphene, apatite, and metallic oxides and sulfides occur sporadically. Epidote, particularly, is abundant in some of the highly hornblendic rocks, and hence the inference that it has developed by the corrosion of hornblende although it does not replace hornblende. Chlorite, very scarce even in thin sections, has been derived hydrothermally from hornblende and biotite.

Augite has been found in hornblendic rocks at one locality in the Beaverdam Creek area and on the dump at the Ross tin mine near Gaffney. In the augite at the Beaverdam Creek locality $Z \wedge c = 48°$, and maximum refractive index is 1.720; in that at the Ross mine $Z \wedge c = 43°$, and maximum index is 1.705. Both are practically colorless in thin section but pale olive green in hand specimen. The crystals range from a fraction of a millimeter to more than 2 inches in length. At both localities the augite is associated with the ordinary bluish-green hornblende, and the relations of the two minerals in thin section throw little light on their relative age.

At Beaverdam Creek, massive garnet has developed around many of the augite crystals which commonly contain swarms of extremely small vermicular bodies. These were examined through an oil-immersion lens, and they appear to consist of quartz. Similar but coarser vermicular quartz in spodumene of the pegmatites is later than the spodumene. The hornblende does not show these alteration (?) effects. At the Ross mine, the augite is very coarse-grained, moderately fractured, and embayed by aggregates of finer-grained hornblende. The rock contains irregular aggregates of calcite whose origin is not apparent. The evidence cited indicates that the augite is earlier than the hornblende at these two localities, but the relatively common occurrence of the hornblende in impure limestone, without augite, shows that the early development of augite was only sporadic and was not essential to the development of the hornblende throughout the belt.

In a few places, highly hornblendic gneisses have been altered to biotite schist at contacts with pegmatite. Accurate measurements of the thickness of the biotite selvages could not be made, but the thickness cannot be more than a few feet, and is probably a few inches. The schist contains greenish-brown tourmaline. Analyses of the biotite given by Hess and Stevens (1937, p. 1044) show the presence of unusual amounts of the rare alkalies and of fluorine.

MINOR TYPES

General statement.—The rocks to be described occur in bodies that are smaller than those of any other rocks except some of the carbonate-silicate types, and more widely

separated than those of any others including the carbonate-silicate types. The augite and enstatite rocks weather to saprolites closely similar to those derived from some of the more feldspathic hornblende and biotite gneisses. They may, therefore, be somewhat more extensive than can be determined even in detailed mapping, but not sufficiently so to be classed as major types. The so-called soapstone and highly chloritic rocks, however, weather to distinctive saprolites, and their subordinate status has been well established, as has that of rocks high in tourmaline which are associated only with pegmatite.

Augite gneiss.—Rock containing augite without hornblende was found at only one place in the area. The locality is 0.6 mile southeast of Grover and 0.2 mile south of the State line. The rock crops out as a thinly layered, northwest-dipping ledge whose weathered surface closely resembles that of the less mafic, impure carbonate rocks; the rock, however, contains no carbonate. It consists of irregular, fine-grained white aggregates and coarser-grained pale olive-green aggregates, both of which are elongate parallel to the layers of the rock, giving it a weak foliation. The white aggregates consist of anhedral plagioclase (An_{42}) and quartz in about equal amounts. Albite and pericline twinning are present but not common in the plagioclase.

Most of the pale-green aggregates consist of augite which, in thin section, is colorless and nonpleochroic. Its optical properties are: $Z \wedge c = 44°$; birefringence 0.03 (α 1.675, γ 1.705); $2V$ (+) moderate. Many of the crystals reach a length of 0.3 inch, and all are embayed by and contain grains of the plagioclase and quartz. The grains that appear in thin section to be enclosed are probably parts of deeply embaying aggregates oriented differently.

Anhedral to euhedral crystals of sphene and less abundant apatite occur throughout the rock. No opaque mineral is present.

Enstatite gneiss.—A medium-grained, grayish-brown, well-foliated gneiss of micaceous appearance crops out 200 feet east of the Ross tin mine, 1 mile northeast of Gaffney. At first glance, the rock appears to be one of the feldspathic biotite gneisses common to the region, but a brown mineral with strong prismatic cleavage is apparent under the hand lens. In thin section, the brown mineral, enstatite, is the most abundant mineral in the rock and is oriented parallel to the layers. The enstatite is anhedral to subhedral, only slightly poikilitic, and has the following optical properties: parallel extinction; birefringence about 0.01 (α approximately 1.655, $\gamma < 1.670$); $r < v$; $2V$ (+) moderate; Z pale brown $> X$ and Y paler brown, almost colorless.

Anhedral plagioclase (An_{22}) and less abundant quartz make up the matrix of the rock and, together, are more abundant than enstatite. A little brown biotite with a faintly greenish cast occurs sporadically with the enstatite and is almost as coarse-grained. For the most part the two minerals appear to be merely intergrown, but a few biotite flakes penetrate and embay the enstatite; they appear at least to be later than the enstatite.

Sparse minerals include rutile, an opaque mineral, and a very little tourmaline. None of these shows any particlar association with other minerals.

Quartz-tourmaline gneiss.—Tourmaline and quartz have largely replaced muscovite schist near some of the pegmatite bodies in the area, and the rock thus formed is granular. Only one outcrop of fresh rock of this type was found. It occurs in mus-

covite schist near the major contact with hornblende-biotite gneiss in the south part of the Beaverdam Creek area. The rock is a medium-grained, sharply layered, and thinly foliated dark-gray gneiss. The layers and foliation parallel the foliation of the enclosing schist, the contact between the schist and the gneiss, and thin layers of hornblende gneiss in the schist. The enclosing schist consists largely of muscovite, quartz, chlorite, biotite, and garnet in different proportions; the chlorite was derived from the alteration of biotite, remnants of which are common.

In thin section the principal minerals of the tourmaline-bearing rock are quartz, tourmaline, muscovite, and garnet in order of decreasing abundance. The quartz is finer-grained than and embays the other minerals and is undoubtedly secondary. The tourmaline is anhedral to euhedral, unaltered, and crudely zoned; the cores of the crystals are commonly light greenish blue, and the outer parts light to medium brownish green. The muscovite is similar to that in the ordinary schist. The garnet is subhedral to euhedral and formed early; some of the crystals are moderately fractured and veined by tourmaline.

Subordinate minerals are biotite, chlorite, apatite, and an opaque mineral. The biotite is confined to certain layers, and some of it has altered to chlorite; the two minerals commonly intergrade in a single mica flake. Chlorite occurs very rarely outside the biotitic layers. Only three garnet crystals, out of dozens in a thin section, are in contact with chlorite. Two of these are veined by the chlorite, and the third touches chlorite at only one place around its rim. Even there the chlorite may be an alteration product of sporadic biotite, for garnet is abundant in the biotite layers, yet shows no relation to the chlorite there.

"Soapstone."—Keith (1931, p. 4) describes "basic" rocks that he mapped together as "hornblende hypersthenite or pyroxenite, hornblende-hypersthene peridotite, and olivine gabbro grading into peridotite, picrite, and amphibolite." He states that all these occur in lenticular or oval bodies and have been altered largely to soapstonelike rocks.

Not all these mafic rocks were investigated, but one occurrence of particular interest was found near the north end of the Beaverdam Creek area. The country rock here is hornblende-biotite gneiss. It encloses an L-shaped body of very coarse-grained mafic rock that weathers brownish green. The weathered rock is rather soft, and attempts have been made to saw out slabs for hearthstones, but the fresh rock is as hard and tough as the enclosing gneiss. The coarse-grained rock contains irregular dark olive-green hornblende crystals, many of which exceed an inch in length, enclosed in a medium-grained aggregate of white minerals and the same kind of hornblende. The hornblende has the same general optical properties as that in the hornblende-biotite gneisses, already described. It contains swarms of a fine-grained opaque mineral and shows slight alteration to biotite. The large hornblende crystals have extremely hazy outlines and are megascopically poikilitic. The white minerals are plagioclase (An_{73}) and quartz. The plagioclase is by far the more abundant and occurs in lath-shaped crystals which are mildly fractured and sericitized along the fractures. The rock also contains a little clinozoisite.

The reason for the coarse grain of the rock is not evident in thin section, and a single meager exposure of the contact gives no genetic evidence. The limbs of the L paral-

lel the trends of two prominent sets of joints in the adjacent area. Pegmatite was emplaced largely in joints in this area. Possibly, therefore, granitic or pegmatitic solutions that had deposited their magmatic constituents nearer the source may have accumulated in joints here, effecting partial recrystallization of the ordinary adjacent hornblende gneiss. Thus, the poikilitic texture of the abnormally large and irregular hornblende crystals may be the result of late development as is true of the tremolite in type (4) and the hornblende in type (6) of the carbonate-silicate rocks.

Chlorite gneiss and schist.—Minor amounts of chlorite have been recorded in the preceding descriptions. In some rocks its derivation from biotite is clear in thin section, but in most of them it appears not to have been derived through the alteration of any other mineral, but to have crystallized under late-stage conditions of low temperature and excess water and magnesia.

Rocks in which chlorite is the dominant or characteristic mineral, however, are relatively scarce and occur mostly with the carbonate-silicate rocks in the Kings Mountain area. (*See* Plate 2 and the discussion of stratigraphic relations of the rocks.) Here they are interbedded with pure and impure limestones and with the silicate rocks that overlie the limestones. The chloritic rocks are the most deeply weathered and no samples of them suitable for petrographic study could be collected. The large amount of clay in some chloritic saprolites suggests the former presence of feldspar, and the invariably advanced stage of weathering suggests even more strongly that calcite was present and that the fresh rock is carbonate-silicate rather than silicate. The chlorite is deep bluish green; specimens collected at two localities are optically negative, and the index of refraction parallel to the cleavage is about 1.60.

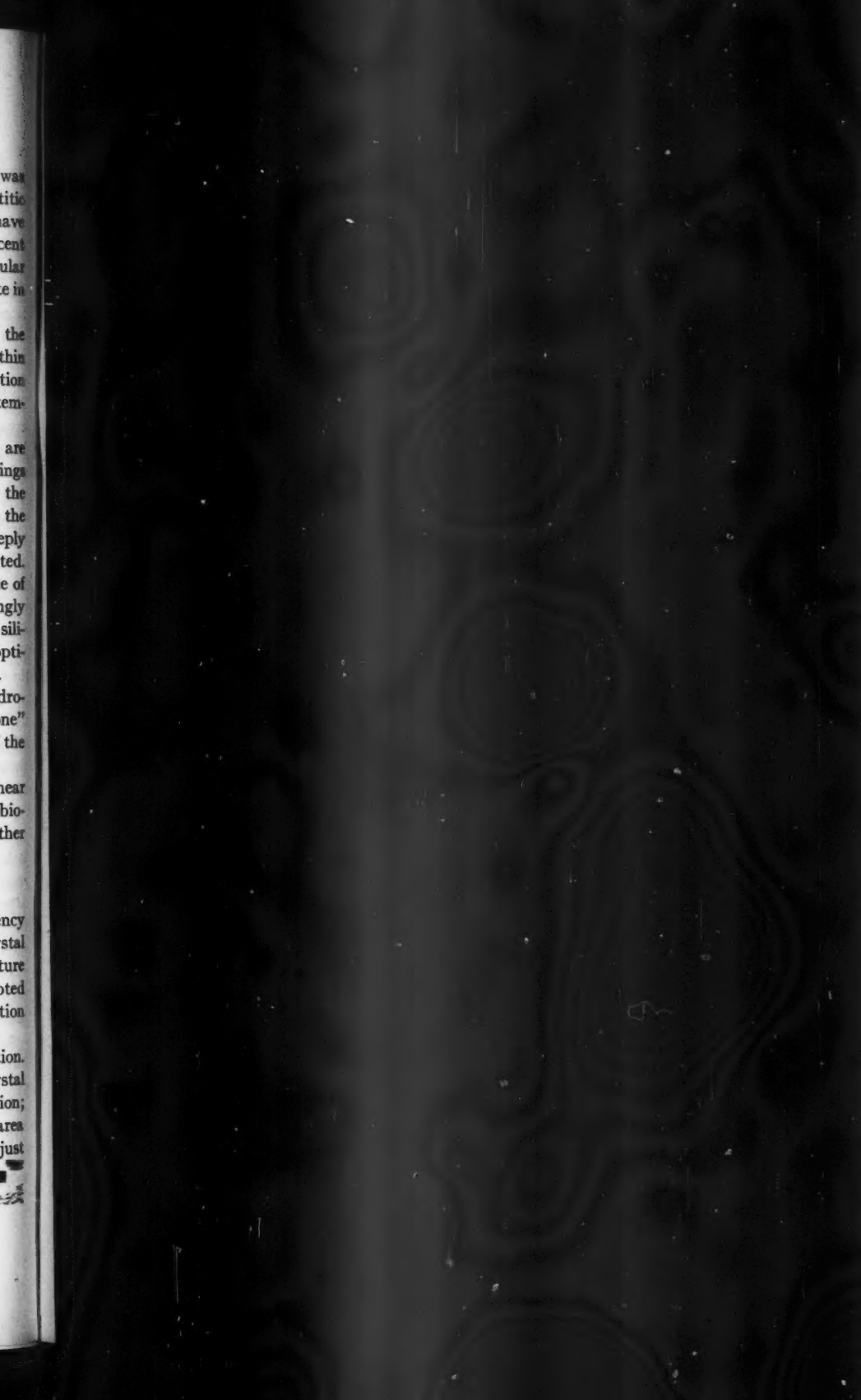
An unusual variety of highly chloritic coarse-grained gneiss was formed hydrothermally as a selvage of the coarse-grained hornblendic rock described as "soapstone" in the Beaverdam Creek area. The selvage is 5 to 10 feet thick, and the texture of the hornblendic rock is clearly preserved in it.

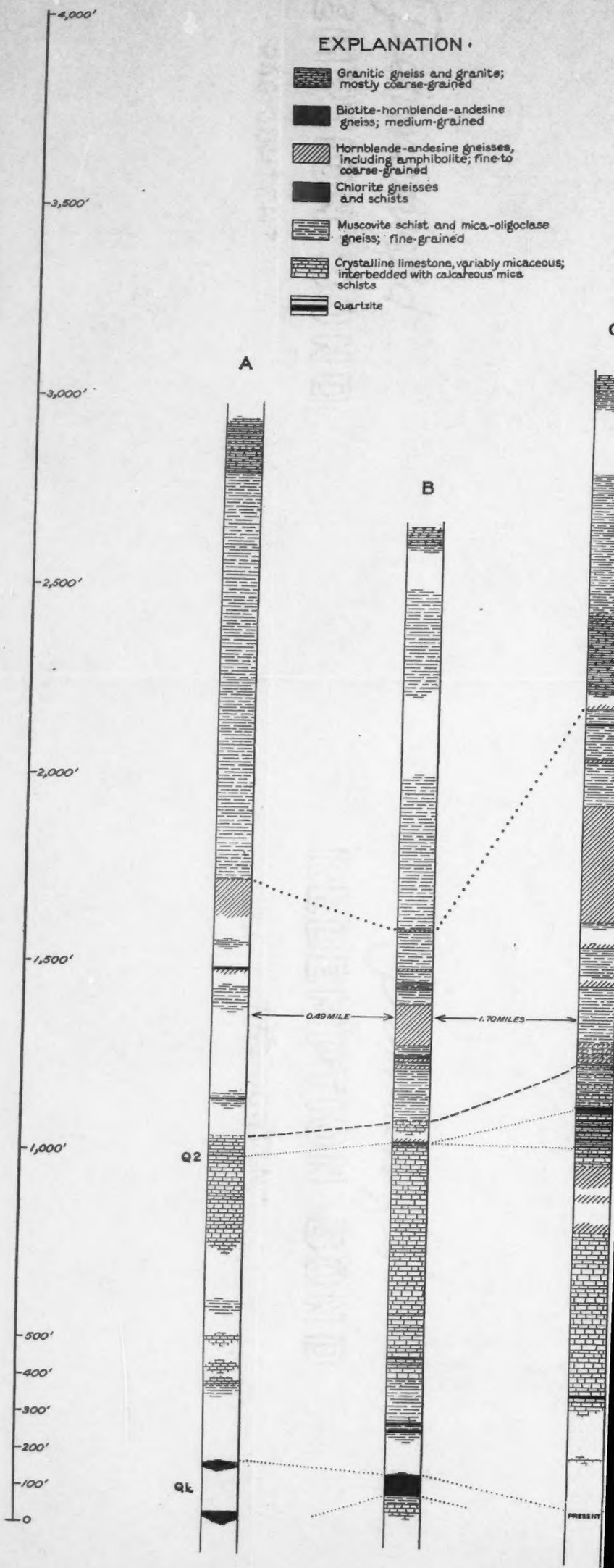
Another unusual variety of chloritic rock, which crops out at the Ross tin mine near Gaffney, is a nearly pure, coarse-grained chlorite schist that appears to be altered biotite schist. It occurs in layers several feet thick interlayered with rocks of other types in a sequence that includes the enstatite gneiss already described.

TEXTURE

The texture of the country rocks is largely crystalloblastic, but there is a tendency toward granoblastic texture in feldspathic types that contain little mica. Crystal boundaries are sharp and in general rounded to semiangular. Crystalloblastic texture is believed to denote simultaneous crystallization of associated minerals, but, as noted in the descriptions of some of the carbonate-silicate rocks, successive crystallization is strongly indicated.

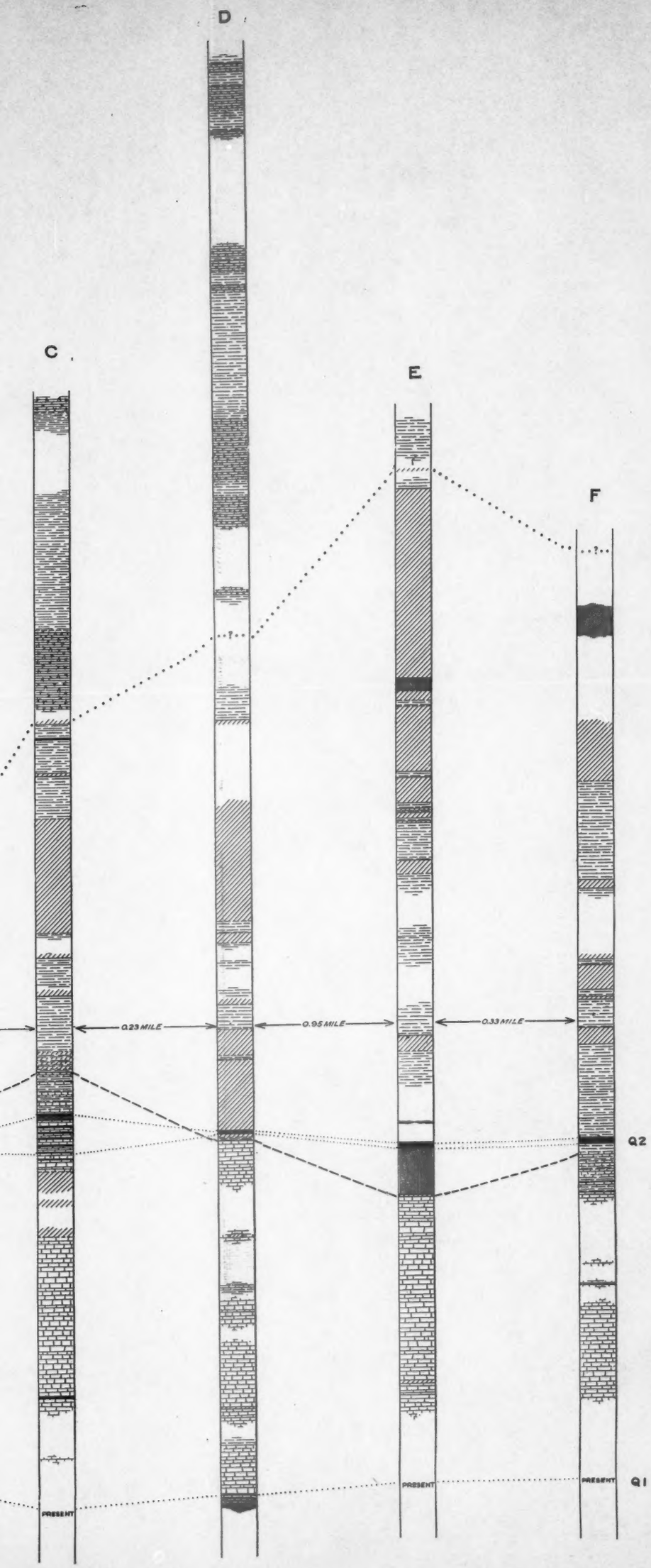
Of 61 thin sections of the country rocks, none show severe crushing or granulation. In 14 of the sections the minerals are moderately fractured, practically every crystal showing one or more fractures along which there was rarely any differential motion; in none was there motion enough to displace any part of the crystal beyond the area occupied by the crystal prior to fracturing. In 12 sections fractures such as those just





COLUMNAR

Plotted from outcrops on and adjacent to li



OLUMNAR SECTIONS
djacent to lines A, B, C, D, E, and F shown in Plate 1

described occur in only about 20 per cent of the crystals. The remaining 35 sections show a negligible number of fractures in random crystals or none at all. In general, undulatory extinction of quartz is proportional to the abundance of fractures but is not strong in any section.

This evidence does not, of itself, indicate that the rocks have never been subjected to more intense deformation; it shows only that the present minerals have never been more severely deformed and that they crystallized after the rocks had acquired their present steeply tilted attitude. The evidence applies, however, to the minerals of the impure limestone as well as the silicate rocks; further, the silicate minerals in the impure limestone, some of which occur as late-formed porphyroblasts, are mineralogically as well as texturally identical with those in the silicate rocks. Finally, there is a total lack of relict textures and structures in all varieties of the rocks. The similarity of the silicate minerals, irrespective of the presence of carbonates, indicates that they all have had the same metamorphic history. Inasmuch as the silicate porphyroblasts in the impure limestones clearly have not been formed by the recrystallization of minerals previously granulated, there remains no basis for inferring this sort of origin for the same minerals in the noncarbonate rocks.

This conclusion, as well as the actual composition of the silicate rocks, is strongly at variance with the designation of these rocks, on the geologic map of the United States (1932), as "albite-chlorite schist and garnetiferous phyllonite." On this map, the limestone is shown as physically separate from the silicate rocks, but such a distinction cannot be made on the basis of detailed mapping, as is brought out in the following section.

AGE RELATIONS OF THE COUNTRY ROCKS

KINGS MOUNTAIN AREA

Physical relations of the rocks.—The Kings Mountain area is underlain by a greater variety of the country rocks than was found in any other part of the belt, and the structural relations of the rocks are better exposed there. The principal drainage is parallel to the strike, and the subordinate drainage transverse. Channels of the subordinate streams in many places expose continuous sections of the rocks across the strike. The details of sections in adjacent channels commonly differ owing to the lenticular structure of beds of all types of the rocks and intergradation of different lithologic units.

To compare the rock successions in different parts of the area, six columnar sections were plotted from the outcrops that occur on and adjacent to lines A, B, C, D, E, and F in Plate 1, with the two persistent zones of quartzite, Q1 and Q2, used as a common basis for correlation. These are not true stratigraphic sections because the rocks dip northwest, and consequently the outcrops are progressively lower down the dip from southeast to northwest; but the attitude of the rocks and the direction of surface slope are the same along the six lines, and the sections, therefore, have equivalent relations to the local stratigraphy. The sections are shown in Plate 2 which records true thicknesses of the different units. The layers of mafic carbonate-silicate rocks, inter-

bedded with the schistose limestone and the quartzite of zone Q2, are shown as hornblende gneiss to which their composition, exclusive of calcite, corresponds. Bodies of pegmatite have been omitted. The sections show at least six interesting and important features:

(1) The lower parts of the sections are dominated by micaceous limestone and dolomite, which constitute Keith's Gaffney marble. The upper parts, exclusive of the younger granitic rocks, consist entirely of muscovite schist, containing some fine-grained mica gneiss, which Keith considered a part of his Carolina gneiss.

(2) Quartzite is interbedded with both carbonate and silicate rocks, but the two persistent zones, Q1 and Q2, which Keith regarded as the same unit of his Kings Mountain quartzite, are definitely included in the carbonate rocks. They are not separated from the carbonate rocks by "graywacke and schist" (Keith's Blacksburg schist).

(3) Highly micaceous limestone (in places graphitic) and carbonate-silicate rocks, which theoretically constitute Keith's Blacksburg schist, occur irregularly in the limestones; they do not constitute a stratigraphic unit.

(4) The interval between the uppermost occurrence of limestone and the lowermost occurrence of muscovite schist free from layers of mafic rocks differs widely in thickness in the different sections. This interval includes alternating layers of mafic gneisses and muscovite schist whose erratic thickness and distribution are similar to those of the limestone and schist below. The composition of the mafic gneisses as described is identical with that of the carbonate-silicate rocks in the limestone except for the absence of calcite.

(5) In each of the four sections that show granitic rocks, the lower limit of appreciably thick mafic layers is approximately the same distance below (away from) the invasive granitic rocks irrespective of the position of the upper quartzite zone. In sections E and F, which do not show the granitic rocks, the distance is known to be about the same.

(6) The layers of mafic gneisses (Keith's Roan gneiss) cannot, because of their irregular occurrence, be correlated between the sections, nor can they be mapped together as one formation without including the upper quartzite zone and encroaching on the limestone. Such a procedure would still have to take into account the sporadic occurrence of mafic carbonate-silicate rocks far down in the limestone series.

These features show the transitional relation of the carbonate and silicate rocks and explain the absence of strike faults in the map (Pl. 1), as well as the lack of any basis for the formational contacts shown by Keith. (*See* Figure 2.) They show that the limestone, the carbonate-silicate rocks, the mafic gneisses, the muscovite and phlogopite rocks, and the quartzite interbedded with all of them together constitute a conformable, uninterrupted series that extends from an unknown position below the lower quartzite zone upward to the lowermost part of the muscovite schist free from mafic layers. Hence, if the simple carbonate rocks are to be regarded as Keith's Gaffney marble (Cambrian), the formation must necessarily include his Kings Mountain quartzite (Cambrian), his Blacksburg schist (Cambrian), and parts of his Carolina and Roan gneisses (pre-Cambrian). As the series is structurally inseparable, its stratigraphic relations must involve the transition between the carbonate and sili-

cate rocks, and the uneven development of silicate minerals during metamorphism is the key to the transition.[1]

Genetic relations of the rocks.—The silicate porphyroblasts in impure limestone, described in connection with the carbonate-silicate rocks, present convincing evidence that mineral-forming materials were transported within the rocks and that carbonate rocks were profoundly changed. The abnormal presence of late albite, microcline, tourmaline, and spodumene in the silicate rocks near pegmatite and granite indicates not only transportation but a widespread source as well, the transportation being by water expelled from the pegmatite and granite as they crystallized.

The pegmatite is intergradational with the granite and is only a subsidiary feature of it. In view of its vast and irregular extent, and of Gilluly's discussion (1937, p. 435–439) of the evidence regarding the water content of granitic magma, it appears that the granite was a source of water sufficient to recrystallize the country rocks and to transport considerable mineral matter probably derived both from the magma and from the rocks traversed. Such transportation presumably would be more active near the source of the water and of the heat than away from it; hence, recrystallization near the source would actually be resolved into reconstitution, the effect of which would diminish away from the source.

Inasmuch as the process accompanied the regional invasion of the magma, it must have been operative over a considerable period of time during which the boundaries of the magma were not stable. Successive rather than simultaneous crystallization of the rock-forming minerals would be expected because of changing conditions. The final result of the process, at any place, could be any one of the following: simple recrystallization; recrystallization with some degree of reconstitution; complete reconstitution; or either of these plus effects that are late, represented by albite, microcline, tourmaline, and spodumene, near contacts with pegmatite and granite emplaced correspondingly late.

The carbonate rocks and the quartzite illustrate the first of these possible results, and the carbonate-silicate rocks the second. As the occurrence of these rocks is of regional scope, and as the granite is of regional extent, the third possible result should also be of regional scope, and the Kings Mountain area provides direct evidence that it was. The transition of the carbonate to the silicate rocks, shown by the columnar sections, takes place westward in the direction of approach to the regionally invasive granite (Keith's Whiteside granite), and the upper limit of simple crystalline carbonate rock is about equidistant from the margin of the granite, though not at the same stratigraphic position, throughout the 4.2-mile length of the area. This limit is shown by the dashed line in Plates 1 and 2; it occurs in some places above the upper quartzite zone and in other places below it. Carbonate-silicate rocks are most abundant near this limit, which consequently marks the eastern extent of strong metamorphism of the carbonate rocks. West of this limit, the carbonate rocks have been partly or completely altered to mafic silicate rocks, and some parts of the interbedded muscovite schists have been altered to fine-grained mica-plagioclase gneisses.

[1] Since the paper was written, the writer has co-operated in a current program of deep core drilling in this area. The results are confidential, but study of the cores fully substantiates the relations of the country rocks as described (December 19, 1943).

As the beds of mafic silicate rocks shown in Plate 2, which Keith regarded as Roan (pre-Cambrian), are strongly metamorphosed or reconstituted parts of the carbonate rocks which he regarded as Gaffney (Cambrian), the upper stratigraphic boundary of the Gaffney coincides with the upper limit of mafic beds. This boundary, which is shown by the heavy dotted line in Plates 1 and 2, is a true stratigraphic contact, for this horizon records a local cessation in deposition of the sediment that was metamorphosed into mafic gneiss. The columnar sections and the strike symbols in Plate 1 show that this horizon is not everywhere at the same structural level although the rocks are strictly conformable. Originally, therefore, the calcareous Gaffney rocks graded upward into shales without a sharp break in deposition.

As mentioned, there is no reliable basis for determining the actual age of these rocks. If the series below the upper limit of mafic beds must have a formational name, the name Gaffney, by which the least-altered rocks have become known, would perhaps be preferable. The two quartzite zones in the series may be known as the lower and upper Kings Mountain quartzite members, to retain the nomenclature of Keith and to emphasize their best development in the vicinity of Kings Mountain. The rocks in the series that are characterized by hornblende, biotite, muscovite, plagioclase, phlogopite, and chlorite are petrologic types rather than stratigraphic members and should be clearly designated as such.

A principal result of the investigation in the Kings Mountain area is greatly to subordinate the possible importance of abnormal structural relations and greatly to increase the importance of petrogenesis in mapping and correlating the metamorphic rocks. The procedure is strongly opposed to the long-standing use, in this region, of physical appearance in dividing and correlating the rocks, for it shows that marked differences in rocks of the same age and origin were effected by metamorphism that was not uniform. The earlier tendency to employ these differences as criteria of age is understandable but unsound.

BEAVERDAM CREEK AREA

Hornblende gneiss and hornblende-biotite gneiss underlie most of the Beaverdam Creek area which is about 2 miles northwest of the extended strike of the rocks in the Kings Mountain area. As shown in Plate 3, the mafic gneisses are bounded conformably on the southeast by interlayered mica schist and hornblende gneiss, and the abrupt difference in lithologic character indicates that the boundary is a major contact. The layers of mica schist and hornblende gneiss southeast of the contact are quite lenticular or perhaps intergrading as indicated by the lithologic symbols, based on outcrops, shown on the map. No limestone, dolomite, quartzite, or carbonate-silicate rocks were found in this area.

The rocks of the area are similar in composition, structure, and texture to those of equivalent types in the Kings Mountain area, and there is no reason to assume a different origin. It appears, therefore, that the mafic gneisses of the Beaverdam Creek area were originally carbonate rocks; only those in the southeast part of the area were interbedded with shales.

All the rocks dip northwest as do those of the Kings Mountain area. The incomplete geologic map of the Lincolnton quadrangle, by Keith and Sterrett, shows no

curvature of the strike of the Kings Mountain rocks as traced to the northeast. Also, the sequence of the rock layers in the two areas is not even approximately similar, and the absence of quartzite in the Beaverdam Creek area is particularly significant. For these reasons, the rocks of the Beaverdam Creek area appear to be stratigraphically higher than those of the Kings Mountain area.

EFFECT ON THE STATUS OF THE CAROLINA AND ROAN FORMATIONS

The Carolina gneiss.—The name Carolina gneiss was first used by Keith (1901, p. 2) in the Washington folio and afterward (1903, p. 2) in the Cranberry folio where its derivation from the micaceous rocks of the Carolinas is stated. The formation, as mapped by Keith, is more extensive than any other in the Southern Appalachians. It consists mostly of mica schists and gneisses with a very considerable range in mineral composition, texture, and structure. Layers of hornblende gneiss are common in the mica schists and gneisses, and these have been regarded as metamorphosed intrusive sheets of mafic igneous rock (the Roan gneiss). The micaceous and hornblendic rocks, as in the Kings Mountain area, are commonly so intimately interlayered that only the dominant rock can be shown except on maps of very large scale. The mica schists and gneisses also contain, in different parts of the Southern Appalachian region, well-bedded crystalline limestone, dolomite, and marble, and Keith considered them parts of the formation.

The Carolina gneiss, because of its great extent and diverse rocks, has been a source of much discussion, the gist of which is that the rocks are crystalline and foliated, and therefore pre-Cambrian. The secondary foliated structure of the rock layers ordinarily receives more attention than the mutual relations of the layers although, at least in the area described in this paper, the layers themselves are of primary origin and consequently of primary importance.

The work on which this paper is based was carried on in a relatively small belt, and the present discussion cannot be expected to apply to Keith's formation as a whole, although the rocks studied extend indefinitely beyond the bounds of the belt. Facts bearing on the status of the formation in and adjacent to the belt described in this paper are as follows:

(1) Micaceous rocks of Carolina type are interbedded with every other major type of metamorphic rock in the belt.

(2) Among these types are crystalline limestones that clearly deserve a formational status apart from that of great thicknesses of micaceous rocks that do not contain limestone.

(3) Also among these types are mafic carbonate-silicate and silicate rocks which are stratigraphically inseparable from the limestone.

(4) The micaceous rocks interbedded with quartzite and limestone are certainly metamorphosed shales, and their petrologic similarity and structural conformity with all other micaceous rocks in the belt strongly indicate the same origin for all of them.

These facts indicate that the term Carolina gneiss has been used in this belt to designate metamorphosed shaly rocks wherever they occur in noteworthy quantity, and that it has lithologic but not correlative value.

The Roan gneiss.—The name Roan gneiss was used first by Keith (1903, p. 2) in the

Cranberry folio. The formation consists of thinly to thickly layered, strongly to weakly foliated hornblendic gneisses and was named from exposures on Roan Mountain, which Keith later described (1907, p. 3). The layers of hornblende gneiss alternate with layers of mica schist and gneiss in many places. The hornblende and hornblende-biotite gneisses of the area studied are typical Roan rocks, and their alternation there not only with mica schists and gneisses but with other rocks as well has been described.

Keith has shown that the Roan rocks have as widespread occurrence as the Carolina rocks, with which they are so intimately associated, but are less abundant. He regarded the hornblende gneisses as sills of metamorphosed mafic igneous rocks and mapped them as pre-Cambrian. The evidence obtained in the belt studied, however, shows that the Roan rocks in the Kings Mountain area were originally pure or impure calcareous beds of the Gaffney formation, and not older igneous rocks. Identical rocks in the Beaverdam Creek area, which also are shown as Roan by Keith in the incomplete manuscript geologic map of the Lincolnton quadrangle, do not occur at the same stratigraphic position and may be higher stratigraphically. The name Roan, therefore, has only lithologic significance in this belt.

Both Sloan (1908, p. 237) and Keith (1931, p. 6, 10) have described the intergradation of some of the limestone with carbonate-silicate rocks containing amphiboles, pyroxene, biotite, epidote, quartz, and microcline. Neither writer drew any conclusion from these facts, presumably because the part played by emanations from intruding granitic magma was not recognized. Too, the small-scale base maps and the time available apparently did not permit the detailed mapping of especially significant areas. In contrast, the genetic relation between the carbonate and mafic silicate rocks, as described in this paper, was established only after 14 months of detailed plane-table mapping on large scales and related petrologic study.

Probability of diverse origin.—The writer does not imply that all the rocks mapped as Carolina elsewhere in the Southern Appalachians were formed by the metamorphism of shale, nor that all mapped as Roan were formed by the metamorphism of limestones. Keith (1931, p. 3) states that the Roan rocks in the region that includes the belt described herein include diorite, but all dioritic rock seen in the present study is physically a part of the layered hornblende and hornblende-biotite gneisses described and has the same mineral composition and microscopic features. Laney (1910, p. 21, 45–52, 56–57), however, has described intrusive diorite in the Gold Hill mining district, 50 miles to the east. He did not correlate the diorite with any other formation, but the relative age that he assigned to it indicates a much younger age than that assigned by Keith to the Roan.

Large areas in the Piedmont province are underlain by interlayered volcanic rocks that include andesite, andesitic tuff and breccia, and greenstone; these are commonly interlayered with bedded sericitic slate, rhyolite, and felsic tuff and breccia. The nature and occurrence of these rocks have been described in detail by Laney in the Gold Hill district (1910, p. 34–45) and in the Virgilina district (1917, p. 18–34); by Pogue (1910, p. 27–68) in the Cid district; and by Stuckey (1928, p. 16–22) in the Deep River region. The volcanic rocks are pre-granite in age. As their names suggest, the mafic rocks have the approximate composition of the hornblende

and hornblende-biotite gneisses described above, and, if recrystallized, probably would be converted into similar mafic gneisses interlayered with mica schists and gneisses formed from the felsic rocks. Inasmuch as the volcanic rocks are known to have been invaded by Carboniferous granite in various parts of the Piedmont, quite possibly large parts of them have been recrystallized to form interlayered rocks of Roan and Carolina types.

Although the available information on the problem is as yet meager, rocks having typical Carolina and Roan features probably are diverse in origin, and consequently diverse in age, in different areas. The original rocks of Carolina type certainly included shaly rocks, a few carbonate rocks whose status is questionable, and possibly felsic volcanic rocks. The original rocks of Roan type certainly included calcareous sediments, probably intrusive diorite, and possibly mafic volcanic rocks. It seems reasonable, therefore, that detailed mapping in other areas may divide the rocks that have been included in the Carolina and Roan formations into distinct stratigraphic units or parts of units wherever differences of origin can be demonstrated. For this purpose, mere contrasts in the average mineral or chemical composition and physical appearance of the metamorphic rocks are not sufficient. The important factors are the detailed structural relations of the rock layers and the comparative genetic history of the rocks. The relations of the rock layers can be studied adequately wherever this primary feature is well preserved, regardless of the extent of recrystallization or reconstitution. The genetic history of the rocks, however, can be studied adequately only where different degrees of metamorphism are in evidence within a restricted area and where the original character of some if not all of the more highly metamorphosed rocks is clear; the belt of the Carolinas described is a key area of this type. The Carolina and Roan rocks can be subdivided with least difficulty in such areas, and facts established in them can be used to advantage in the study of adjacent areas underlain entirely by strongly metamorphosed rocks.

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Beaverdam
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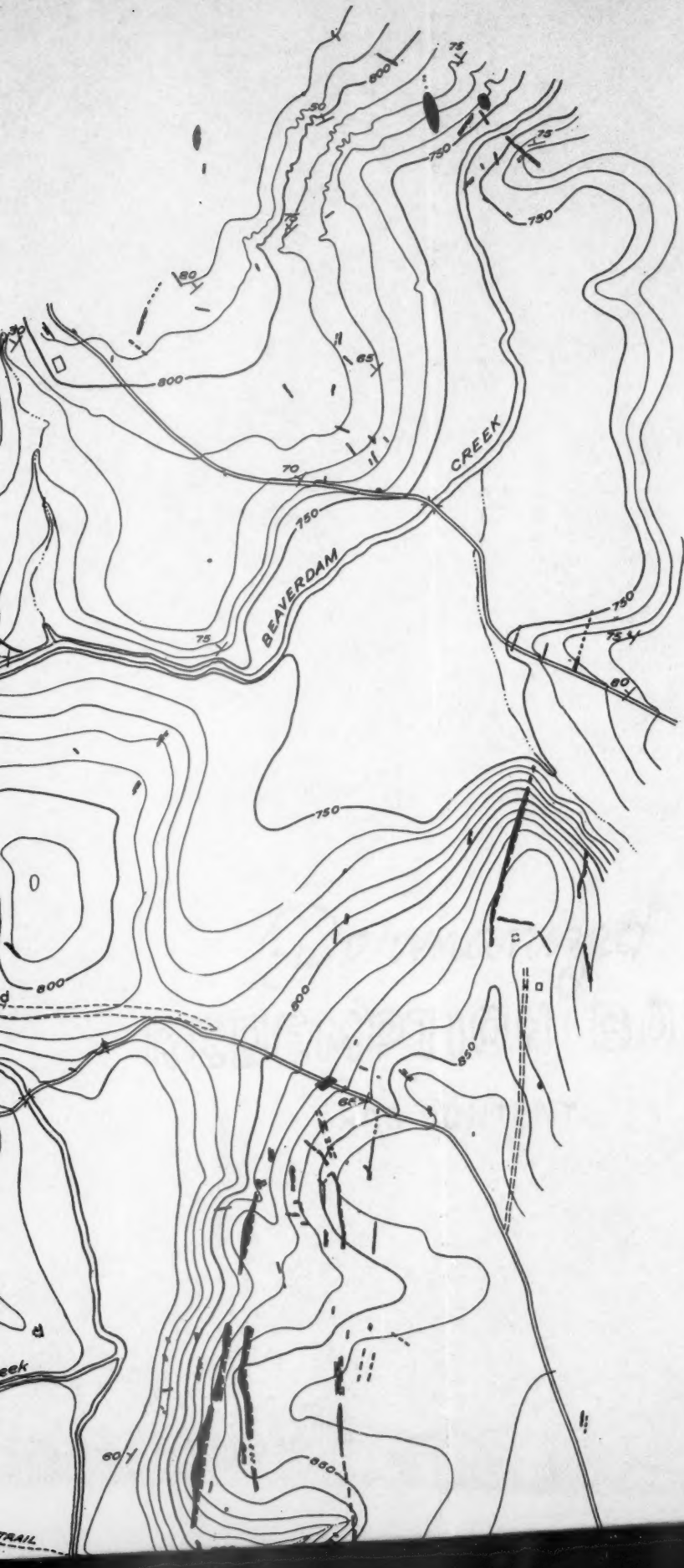
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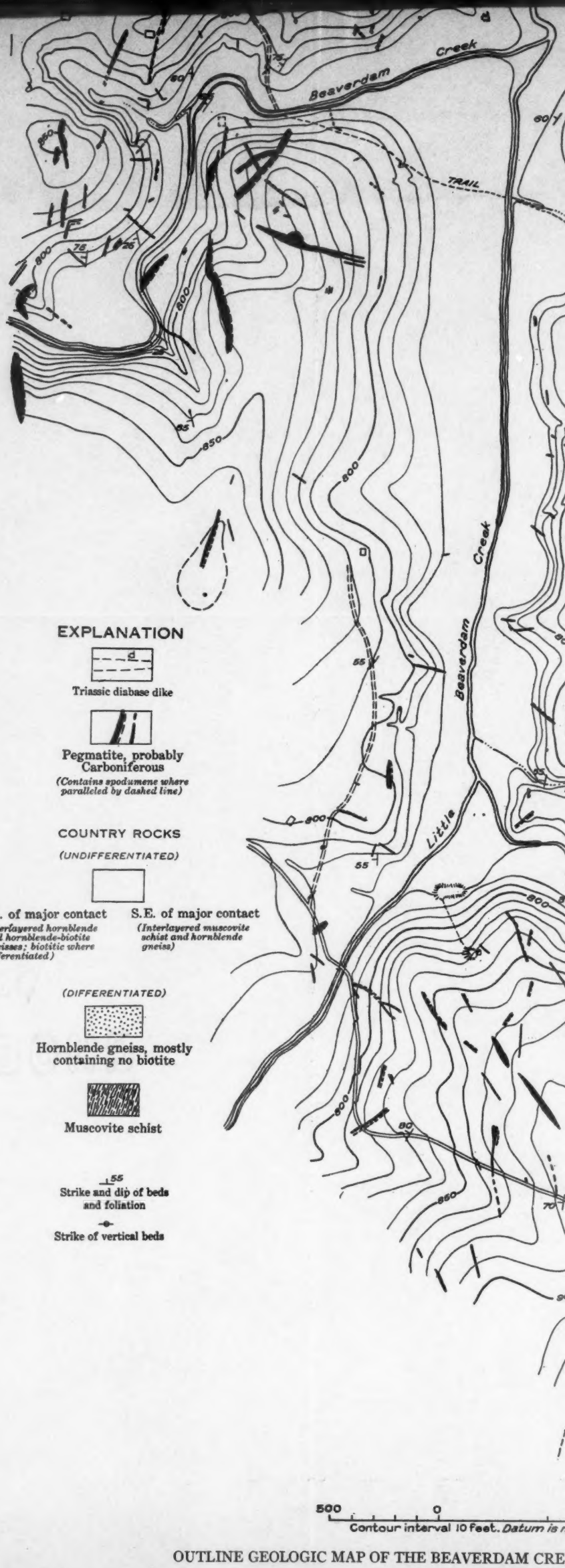

OUTLINE GEOLOGIC MAP OF THE BEAVERDAM CRE

1,000 Feet

Datum is mean sea level

AM CREEK AREA, NORTH CAROLINA

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MILITARY GEOLOGY:
APPLICATIONS OF GEOLOGY TO TERRAIN INTELLIGENCE

BY CHARLES E. ERDMANN

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INTRODUCTION

About a year ago an abstract of a German article on military geology appeared in the *The Military Review* (Command and Staff School, 1943) and called attention to the employment of a geological section of nine men by each German army. Every adversary of these forces has yielded reluctant admiration to their most skillful use of ground, and there is reason to believe that applications of geologic science have made substantial contributions to their successful exploitation of terrain. By their own admission, we know that they have used geology in administrative and operational problems, and it is logical to conclude that they have also found geology adapted to certain phases of military intelligence. This formal usage of military geology is presently in great contrast to its somewhat indifferent use, or even lack of use, by the Army of the United States. Indeed, in our Army less progress in military geology has been made in World War II than in World War I, when authority existed for the assignment of five geologists to each Army, or one for each Corps—despite the fact that the varied geography of the far-flung theaters of the current war and the character of combat within them require much more intense application of every possible method of terrain evaluation than did the fighting in northern France some twenty-odd years ago. This does not mean that our effort in World War II wholly lacks geologic technique. On the contrary, War Department intelligence (Intelligence Division, Corps of Engineers) is being prepared by the Military Geology Unit of the United States Geological Survey, and ground-water geologists of the Survey are functioning with engineer water-supply battalions; but there has been no general recognition of a place for a geologist with combat forces. Nevertheless, some geologic techniques for field forces are being carried out by men of other sciences, such as studies on soil trafficability by certain meteorological sections of the Army Air Force (Link, 1943). Obviously, this situation is the product of a definite need; and the question whether it is being met in the most efficient manner can be argued from the standpoint of the military principle of economy of force. Whatever the nature of the precipitation, once on the ground it becomes a geologic agent operating upon geologic materials, and only the geologist has been trained to analyze the process and

its results in detail. Hence he believes that, given the weather prediction, he is far more able to foresee its effect upon terrain and mobility and operations as a whole than the meteorologist. Because of differences in kind and attitude of bedrock, character and thickness of mantle rock or surficial soil, topography and vegetation, and rate of rainfall, rates of absorption and runoff may change rapidly from place to place. Geologic methods of terrain analysis may reveal unsuspected wet-weather routes in advance of cross-country movement that might otherwise be found only by trial and error or through the favor of friendly inhabitants after the ground is reached; they can certainly indicate in advance of a weather forecast the most favorable of alternative dry-weather routes, or the reaction to traffic of various kinds of ground under different conditions of rainfall, on the chance that unpredicted inclement weather might overtake a field operation in progress.

Reasons for the nonemployment of geology by our Army are probably both administrative and technical. Only the technical reasons need concern us here, for they must be overcome before any administrative progress can be made. The general attitude of the Army toward the military application of any science has been expressed as follows:

> The adaptation of new scientific developments to war is gradually making the task of G-2 more complex; at the same time, however, it affords him an additional means for the collection of information. (FM 30-5, par. 14d)

This quotation is especially pertinent with respect to geology because that science does afford an additional means of information that no other can supply, and, as will be shown, if properly applied it should simplify rather than complicate the task of G-2.

Why then, one may ask, is it not put to greater use? Perhaps there is some question as to its proper place in Army organization. Another reason may lie in the very nature of geology, for it is admittedly a "circular subject"; that is, there appears to be no obvious or convenient place where a layman can grasp it. Thus, in physical geology consideration of processes presupposes some knowledge of the materials upon which they operate, and discussion of materials leads back again to processes. All the more reason, then, why the various aspects of geology should be handled by those who have been trained in its techniques. On the other hand, the military method of terrain evaluation on the "basis of observation and denial of observation" (FM 5-15, par. 9a(1)) is wholly artificial and incompetent to develop the fundamental characteristics of terrain. Admittedly, it is very practicable and suffices to evaluate the conventional military factors of terrain appreciation, observation, fields of fire, cover and concealment, obstacles, and communications; but it leads away from rather than to the essential elements, which constitute the substance or nature of the terrain itself, and these elements are what actually control whatever view the observer can obtain. Because of this exclusion the soldier is inclined to ask: How can the geologist tell so much about terrain from geology? Insofar as the writer's studies have been carried, only one obscure paragraph of Army doctrine (FM 21-26, par. 40A) gives recognition to this question, and it comes under the heading of "Relief" rather than "Terrain":

As the exact nature of the terrain has a marked influence on military operations, it is important that the military commander of every unit familiarize himself with the 'lay of the land' in which he is operating. This familiarity cannot always be obtained by actual reconnaissance beforehand but often must be gained solely by study of topographic maps. The map, then, must convey to the map reader a definite impression of the ground forms. *The ability to comprehend relief from the map requires an understanding of the way in which the various ground forms have been produced by nature.* (Italics are present author's.)

This realization of the intimate association of geologic agents with land forms, and the ability to interpret their origin and evolution from topographic and geologic maps or aerial photographs, is why the geologic method of terrain appreciation yields superior and often unsuspected technical information that may have practical tactical value, without in any way restricting the scope of other military operations. In fact, it supplements them, and its application assures that no basic factor of terrain will be overlooked. Hence the fundamental contribution of geology to military operations is superior information. The purpose of this article is to suggest the proper place of geology in Army organization, to indicate how well prepared the structure of this organization is to receive it, and to show how geologic data are assembled and converted into intelligence.

PLACE OF GEOLOGY IN TERRAIN INTELLIGENCE

The mutual relationship between geology and terrain, or, as the soldier sees it, the landscape, is axiomatic. There is an equally close connection between land warfare and terrain. Without some good earth the terrain factor would not exist, as in naval warfare. Obviously, then, the common denominator of land warfare and geology is terrain. By substituting geology for terrain in the above equation, its place in our military doctrine is determined at once.

Based upon source of information, military intelligence is classified into War Department intelligence and combat intelligence. Presumably War Department intelligence is carried on in time of peace, and the results obtained are furnished to the field forces prior to operations, but its activities do not terminate with the recognition of a state of war. The Basic Field Manual on Combat Intelligence, FM 30-5, par. 3b, lists numerous topics within its scope, among them military geography and topography. Unquestionably, future revisions of the paragraph cited will include military geology, because the resolving power of geologic analysis, especially with respect to terrain, is much more definitive than that of the pseudo science of geography. War Department intelligence is the very foundation of geologic terrain analysis. Without large highly specialized libraries rich in geologic and topographic maps of all lands, scientific and technical publications of all kinds and in all languages, and a competent analytical staff, the basic compilations could not be made.

Combat intelligence is derived from the interpretation of military information in the field in the presence of the enemy, and its chief concern "is to reduce as far as possible uncertainties regarding the enemy and local conditions and thus assist the commander in making a decision and the troops in executing their assigned missions." (FM 30-5, par. 5a.) The application of this phase of intelligence seems to have been overlooked completely. When focused through an intelligence plan the method of geologic terrain analysis constitutes a most powerful tool whose results may

be either deductive or simply descriptive. This is especially true when it becomes necessary to supplement incomplete information of enemy dispositions by evaluation of his utilization of terrain. German, or German-trained forces, and possibly the Japanese, would seem to be particularly vulnerable to this technique. Under their doctrine it is entirely possible that a military geologist may have been consulted when their arrangements were made. Hence, unless the exigencies of a tactical situation expressly forbid it, one may expect their positions to be outlined by both the form and substance of terrain. Prepared positions almost certainly will be influenced by such control. Counter-intelligence thus demands that estimates of the enemy dispositions be reviewed by our military geologists, who will at least be conversant with the governing factors of the ground. A convenient testing procedure would be to overlay enemy situation maps, insofar as the situation is known, on the various types of terrain maps described below. Other essential elements of information such as prediction of unknown details or obstacles in enemy-held terrain that may affect our own maneuver should be even more amenable to geologic methods of terrain appreciation. The technique may also help to define enemy capabilities by outlining unsuspected routes of approach and conditions of mobility, and so deprive hostile attack of the major elements of surprise—place and time. Without further discussion it may be said in summary that geology has a direct application to the commander's estimate of the situation through the medium of terrain intelligence.

Inasmuch as the military geologist can develop his tactical value most effectively through his contributions to combat intelligence, it seems logical that he should function through the intelligence section of the unit to which he is attached, and because of his preoccupation with information relating almost exclusively to some aspect of terrain it is even more appropriate that his duties be correlated with engineer intelligence. This is the ideal situation because it makes his services available for both tactical and administrative circumstances. The increased scope of these activities will result in the development of additional geologic information and better integration of that available, for it is inherent in geology that the key to a particular question often is discovered miles from the locality where the problem developed. Hence the military geologist should be allowed unusual freedom of movement within his lines for more or less continuous investigation. When requests for terrain reconnaissance are made, the unit intelligence officer should route them through the military geologist for suggestions as to additional items for observation, or for his participation in the patrol. With this possibility in mind, it may be worth while to consider the advisability of revising FM 5-5, par. 286c, *Means of securing information*, to include geologic information; and geologic reconnaissance might be mentioned in the list of special types of reconnaissance, FM 5-5, par. 287c.

TECHNIQUE OF GEOLOGIC TERRAIN ANALYSIS

Much sound material has been written on the technique of geologic terrain analysis, especially by Major Erich Sonne (1935), former Inspector of Fortifications, Western Front, and it is doubtful if any fundamental improvements will be made soon. Future developments will be largely of the nature of refinements or greater

application of detail as larger-scale maps are used for smaller military units, and extension of technique to new problems. Basically the method is an intelligence operation, and in some ways the procedure corresponds to that used for the formulation of an intelligence plan.

Inasmuch as more of a region can be visualized at one time on a map than on the ground, the foundation of the analysis is a chart showing the different kinds of rocks and their relationships. Such a sheet is called a lithologic or geologic map, and is more indispensable to the military geologist than a topographic map, because, in addition to the geology, it always contains information on terrain not determinable from a topographic sheet of the same area, and besides many topographic details can be deduced from it. Geologic maps are now available for most of the land surface of the earth and are always susceptible to refinement as the scale is enlarged. However, if the area to be studied is not so covered, a geologic map will have to be made. A topographic map is also a great help, and the ideal combination is a geologic map on a topograhic base. Although aerial photographs are not maps in a strict sense, they make acceptable substitutes for topographic maps and may show much geologic detail or serve as a base for geologic mapping. With these materials, and his professional knowledge of petrology, structural geology, process, and stage, the military geologist is now ready to develop such essential elements of information relative to terrain as his commander deems necessary for his intelligence plan.

> The essential elements of information constitute the basis for orders governing the search for information. (FM 100-5, par. 203)

Army doctrine on essential elements of information indicates clearly that some of them are susceptible to geologic analysis:

> Essential elements of information for the unit intelligence plan include not only the information required for planning operations of the unit, but also the information required for operations as a whole of the higher units of which it is a part. The elements of information required by an engineer unit may relate to hostile forces *but usually they are related to the terrain, natural and commercial resources, and are technical in character.* Determination of the essential elements cannot be made without a thorough understanding of the tactical situation and the expected employment of the engineers. Essential elements of information change with the situation and must be redetermined as often as necessary. (FM 5-5, par. 286b) (Italics are present author's.)

Without exception the essential elements of geologic information can be segregated and illustrated by means of maps. Among the various kinds of geologic maps that have been made to focus the activities of intelligence agencies on the items of information needed to complete a plan or to carry out a decision are the following: water supply, surface waters (lakes and rivers), mobility or route, workability of ground, subsurface drainage, coastal conditions, construction materials, economic geology, and so on. These elements are further analyzed into specific indications by means of a tabular form and cross references to the map by means of appropriate symbols. For example: the geologic map illustrating Major Sonne's article shows three formations that have been subdivided into eight map units. On the corresponding table they are arranged in natural sequential order (youngest at the top). Columns on the left side of the sheet give (1) map color and symbols, and (2) geologic formation names. Other columns to the right list the principal and special characteristics of

the formations with respect to military operations, as (3) kinds of rock, (4) water bearing, sound conducting, (5) occurrence of vegetation, (6) approximate thickness, (7) workability (five classes are listed ranging from workability by spades to compressed air drill with continual blasting), (8) stability (with respect to rainwash), (9) military usefulness (chiefly with respect to concrete aggregate and construction materials), (10) expected exfoliation around reinforced concrete construction, (11) behavior when wet, (12) foundation excavations, trenches, (13) under ground mines, dugouts, (14) drainage conditions, (15) practicability for roads, including infantry. Thus a few words or a figure in each box summarize some particular character, and a glance at the map indicates whether or not it affects the locality considered.

Space does not permit description of other more specialized types of maps and their individual schedules. Obviously, however, a terrain-evaluation folio containing a topographic and a geologic map, together with the series of supplementary maps or overlays that the situation demands, makes a practically inexhaustible handbook on terrain for the ground so covered. Some information is available immediately on almost any military problem involving terrain, whether it be fluctuation of the ground-water table at a prospective airdrome location, bearing power of soil at the site of heavy guns, route location with respect to material for construction and maintenance, effect of artillery fire on ground, or the characteristics of fringing and barrier coral reefs in amphibious operations.

Useful as they may be, however, the folios alone are of limited value because the technical information they contain will usually require individual interpretation or adaptation to specific local situations, as well as constant attention in the way of additions, corrections, and regrouping of information to meet changing or unforseen events. This can be done effectively only by a man on the ground—at the front—the specially trained military geologist functioning through engineer intelligence. It is precisely in this particular station that we lag behind our foes—and to their advantage.

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